A METHODOLOGY FOR THE VALUATION AND SELECTION OF ADAPTABLE TECHNOLOGY PORTFOLIOS AND ITS APPLICATION TO SMALL AND MEDIUM AIRPORTS

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A METHODOLOGY FOR THE VALUATION AND SELECTION OF ADAPTABLE TECHNOLOGY PORTFOLIOS AND ITS APPLICATION TO SMALL AND MEDIUM AIRPORTS

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To Mom, Dad and Jean-Yves

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It is not knowledge, but the act of learning, not possession but the act of getting there, which grants the greatest enjoyment.

−Karl Friedrich Gauss (Letter to Bolyai, 1808)

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SUMMARY

The increase in the types of airspace users (large aircraft, small and regional jets, very light jets, unmanned aerial vehicles, etc.), as well as the very limited number of future new airport development projects are some of the factors that will characterize the next decades in air transportation. These factors, associated with a persistent growth in air traffic will worsen the current gridlock situation experienced at some major airports. As airports are becoming the major capacity bottleneck to continued growth in air traffic, it is therefore primordial to make the most efficient use of the current, and very often, underutilized airport infrastructure. This research thus proposes to address the increase in air traffic demand and resulting capacity issues by considering the implementation of operational concepts and technologies at underutilized airports. However, there are many challenges associated with sustaining the development of this type of airports. First, the need to synchronize evolving technologies with airports' needs and investment capabilities is paramount. Additionally, it was observed that the evolution of secondary airports, and their needs, is tightly linked to the environment in which they operate. In particular, sensitivity of airports to changes in the dynamics of their environment is important, therefore requiring that the factors that drive the need for technology acquisition be identified and characterized. Finally, the difficulty to evaluate risk and make financially viable decisions, particularly when investing in new technologies, cannot be ignored. This research provides a methodology thats addresses these challenges and ensures the sustainability of airport capacity-enhancement investments in a continuously changing environment. In particular, it is articulated around the need to provide decision makers with the capability to valuate and select adaptable

technology portfolios to ensure airport financial viability. Hence, the four-step process developed in this research leverages the benefits yielded by impact assessment techniques, system dynamics modeling, and real options analysis to 1) provide the decision maker with a rigorous, structured, and traceable process for technology selection, 2) assess the combined impact of interrelated technologies, 3) support the translation of technology impact factors into airport performance indicators, and help identify the factors that drive the need for capacity expansion, and finally 4) enable the quantitative assessment of the strategic value of embedding flexibility in the formulation of technology portfolios and investment options. In particular, the development of this methodology highlights the successful implementation of relevance tree analysis, morphological analysis, filters and dependency tables to support the aforementioned process for technology selection. Further, it illustrates the limited capability of Cross Impact Analysis to identify technology relationships for the problem at hand. Finally, this methodology demonstrates, through a change in demand at the airport modeled, the importance of being able to weigh both the technological and strategic performance of the technology portfolios considered. In particular, it illustrates the impact that the level of traffic, the presence of congestion, the timing and sequence of investments, and the number of technologies included, have on the strategic value of a portfolio. Hence, by capturing the time dimension and technology causality impacts in technology portfolio selection, this work helps identify key technologies or technology groupings, and assess their performance on airport metrics. By embedding flexibility in the formulation of investment scenarios, it provides the decision maker with a more accurate picture of the options available to him, as well as the time and sequence under which these should be exercised.

CHAPTER I

MOTIVATION

The air transportation industry has continued to grow over the last decades [297], in spite of being sensitive to rising fuel prices, political instability, pandemics and economic crises [142, 123]. In fact, this industry is now a significant contributor to many countries' Gross Domestic Products (GDP) [271, 5] and a source of employment for about 32 million people around the globe (Figure 1). As a result, this industry, whose development is mainly attributed to continued globalization of business and growth in GDP [271, 35], is described as "an indispensable part of the economic infrastructure" [11].

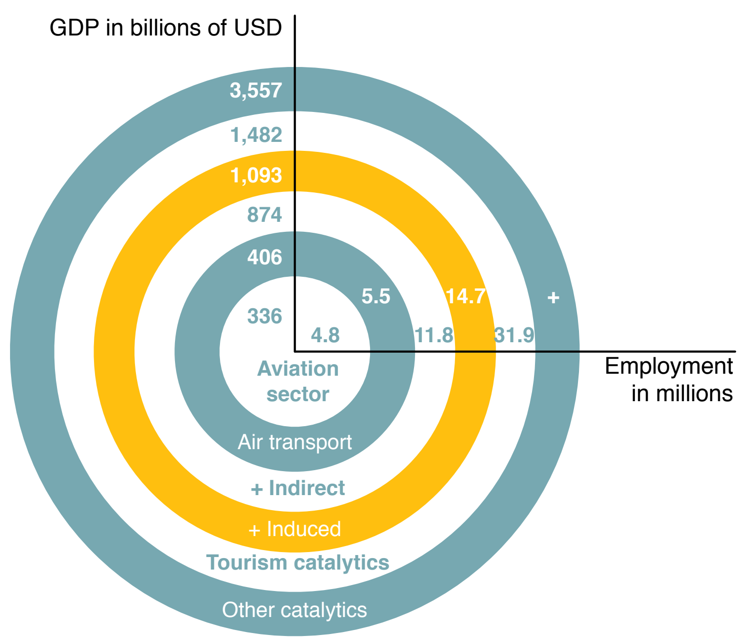


Figure 1: Global economic impact - employment and GDP (2006) [5, 246].

Despite the recent economic downturn and the resulting decrease in congestion, it is expected that the growth in traffic and air travel demand will resume its anticipated fast pace. Regardless of when this will occur, it will bring significant challenges and will carry serious economic consequences, particularly in the United States and in Europe, where the infrastructure in place is often described as lacking capacity and outdated [84]. Also, the size and the complexity of the European and U.S. air traffic systems, along with the concentration of traffic to these regions of the World (Figure 2) will make accommodating future growth and finding solutions to the projected performance and safety issues more difficult. The two following sections provide a description of both U.S. and European air transportation systems. Respective challenges, as well as related plans and efforts to address the future growth in traffic are also examined.

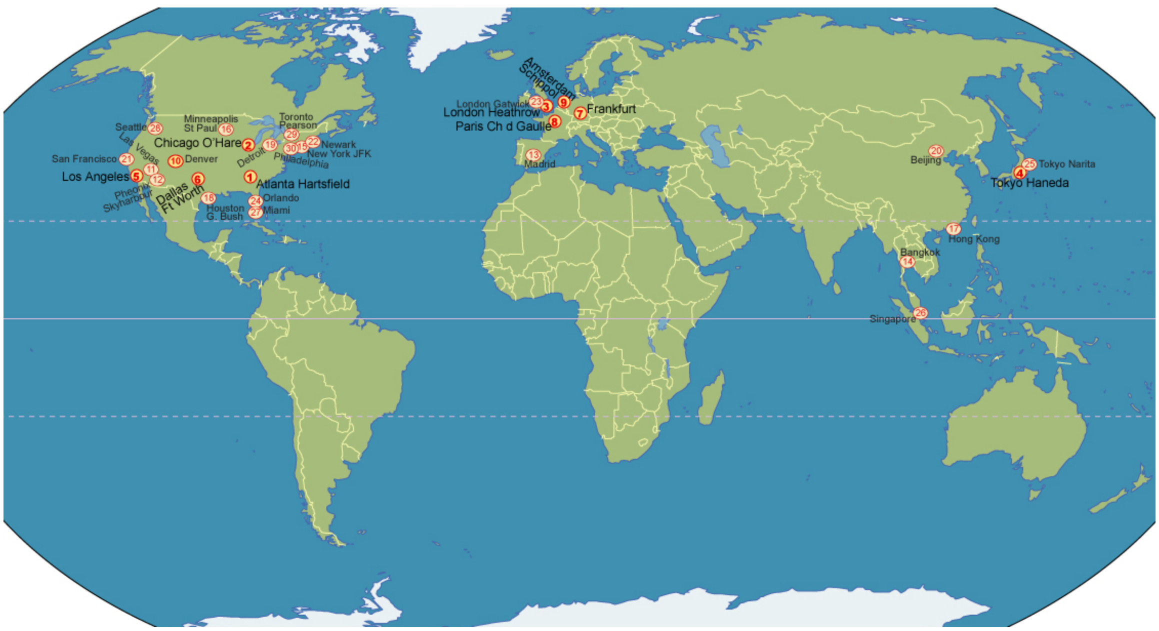


Figure 2: 2004 Passenger traffic at the World's largest airports [7, 174].

1.1 The U.S. Perspective

The U.S. Airspace System is a large, dynamic and complex system that encompasses approximately 40 percent of the world's commercial aviation and 50 percent of the world's general aviation activity [315, 84]. In the United States, "air transportation growth has exceeded GDP growth for the last 50 years and it is the mode of choice for intercity travel beyond 500 miles for both passengers and high-value cargo" [86]. According to a socio-economic demand forecast study conducted jointly by NASA and the Federal Aviation Administration (FAA), in 2003, the air transportation industry brought between 80 to 90 billion dollars per year to the national economy (corresponding to 1 percent of the GDP) and employed 800,000 people [35]. In 2006, the contribution of the air transport industry to North American GDP (United States, Canada, and Mexico) was estimated to be nearly USD 560 billion, with around 5.7 million jobs generated [5]. In the U.S., the civil aviation activity contributed to 5.6 percent of the GDP and 11 million jobs in 2006 [122].

The U.S. Airspace System is composed of approximately 20,000 airports (Figure 3). Among these airports, 3,411 have been identified by the FAA as being significant to air transportation [123], with 3,254 being public owned, 102 being privately owned and 55 being proposed. These airports represent 65 percent of the 5,190 existing public use airports. The passenger traffic is far from being uniform with 30 airports handling about 70 percent of the overall passenger traffic [315]. Passenger traffic is thus concentrated over a few airports, mainly in large metropolitan areas (Figure 4) resulting, as mentioned by Bonnefoy [35], in most of the available airport infrastructure being underutilized. Furthermore, since 1990 and more significantly after 2000, the major legacy carriers in the U.S. underwent major restructuring and gradual downsizing of their fleet, replacing large aircraft with smaller regional jets. The emergence of regional jets, along with the significant growth in low-cost carriers experienced during these years [315], resulted in the number of operations growing faster than the passenger traffic [35]. Also this increase in the number of operations is expected to be reinforced within the next 10 to 15 years by the entry into the market of new types of airspace users, such as Very Light Jets (VLJs) and Unmanned Air Vehicles (UAVs).

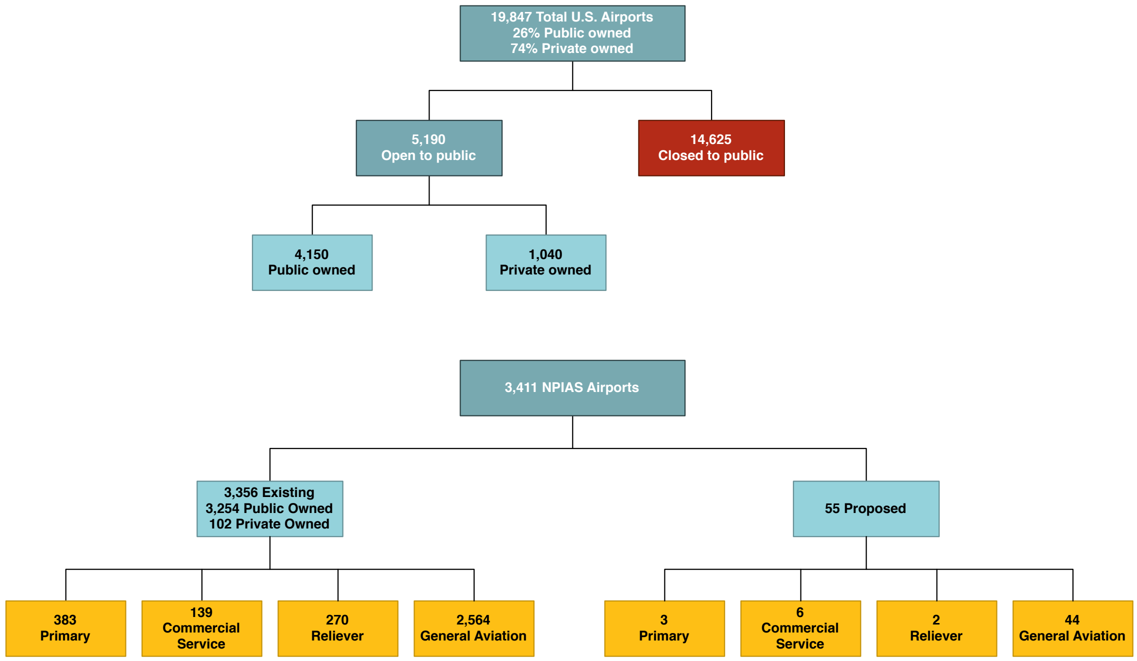


Figure 3: Number of existing airports by ownership and use (January 2008) from [123].

The demand for air travel is expected to keep increasing over the coming decades. In March 2008, Acting FAA Administrator, Bobby Sturgell, announced that “from an operations standpoint, we predict that on average every year from now until 2025, we’re going to add the equivalent of JFK, LaGuardia and Newark combined in to the system" [184]. In that same month, the Secretary of Transportation, Mary E. Peters, announced that by 2025, the equivalent of a carrier the size of Northwest will be added to the system every 18 months, which represent an average increase in revenue passenger miles of 50 billion a year [248]. In 2009, the FAA was also forecasting that “the anticipated 69 percent increase in passengers over the 18-year period between 2007 and 2025 is expected to result from a 56 percent increase in air carrier and commuter operations.’ [123], hence worsening the already existing inadequacies between demand and capacity and reinforcing congestion levels at some major airports [35]. Although the projected doubling (2X) to tripling (3X) of the demand may take more years to materialize than what was previously expected, it raises

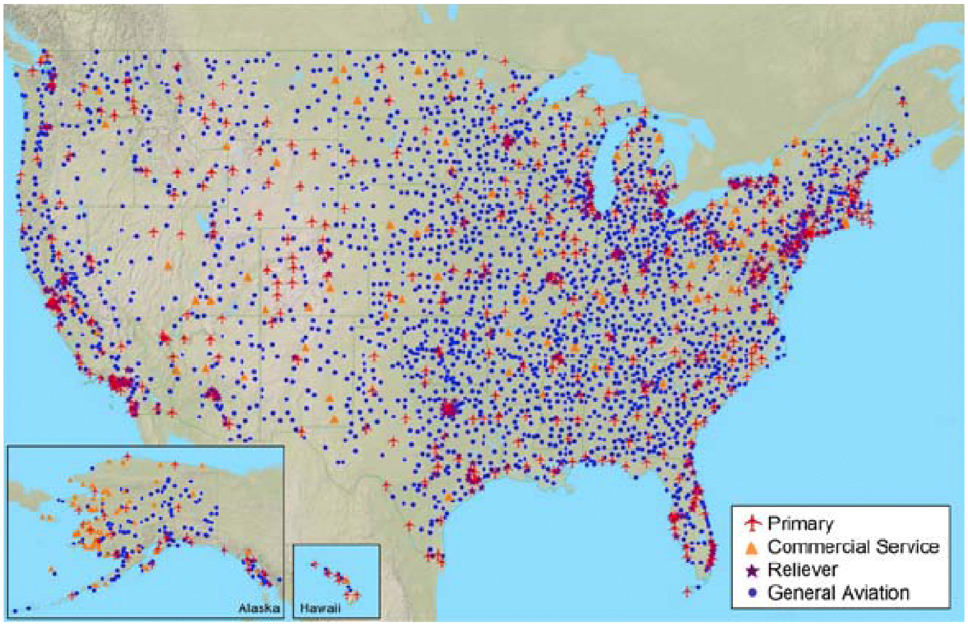


Figure 4: Geography Coverage of the Main U.S. Airports [123].

serious concerns among experts about the ability of the existing air system to accommodate the future growth. These concerns are supported by an all-time record in delays in 2007, with more than 540,000 aircraft that did not take off or land on time [248]. Most of the worry is oriented towards airports that are already experiencing gridlock during peak hours (mostly airports located in metropolitan areas) [158] because their ability to significantly expand is limited [35]. Consequently, the forecast demand and resulting capacity issues will have to be addressed with the existing airport infrastructure [35, 314, 218].

In order to enable the nation to meet its air transportation needs, President Bush signed in December 2003 the "*Vision 100*" legislation (Public Law #108-176) that established the Joint Planning Development Office (JPDO) to develop "the design and deployment of a modernized aviation system called the Next Generation Air Transportation System (NGATS, now called NextGen)" [121]. The JPDO is an interagency structure composed of the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), the Departments of Defense, Transportation, Homeland Security and Commerce, and the Office of Science and Technology Policy, whose goal is to coordinate federal efforts in applying R&D resources to enable the NexGen [148].

The NextGen has been more precisely defined by the FAA administrator Marion C. Blakey as “an integrated plan using modern technology, updated procedures and new equipment, to take us beyond ground-based radar technology and voice direction, and into the second century of aviation with satellite-based operations, updated communications and automation, and improved weather and traffic management capabilities” [121]. This integrated plan should allow the national airspace to accommodate a tripling in demand [313]. Its goals have been more precisely described in the *Next Generation Air Transportation System Integrated Plan*" [177] released in 2004. The path and implementation schedule to achieve all of the NextGen commitments can be found in the “*Operational Evolution Partnership*” (OEP), the OEP being “the FAA’s 10-year rolling plan to increase both the capacity and efficiency of the NAS while enhancing safety and security" [28]. The Joint Planning and Development Office (JPDO) also took the lead in developing a Concept of Operations (ConOps) for the NextGen [179]. In 2005 it presented a high-level vision for the key operating principles and characteristics of NextGen in the “*NGATS Vision Briefing*”. JPDO’s work is described in a document entitled “*Concept of Operations for the Next Generation Air transportation System*” [179], which “identifies key research and policy issues that need resolution to achieve national goals for air transportation”. In many cases, this document presents ‘aggressive’ concepts that have not been validated, but are envisioned to “maximize benefits and flexibility for NextGen users” [179]. More particularly, the JPDO “envisions a combination of new technologies enabling significant growth at large airports and increased operations at underutilized airports to absorb the expected increase” [289]. Finally, more recently, in 2010, the JPDO refined a Concept of Operations (ConOps v3.2) for the Next Generation Air Transportation System [181] and added the Enterprise Architecture Version FY13 to the NextGen Joint Planning Environment (JPE) [176]. It also released the Integrated Work Plan (IWP) Version FY13 and the Executive Summary for the Integrated Work Plan (IWP) Version FY13 [175], which provide information about operational improvements, enablers, policy issues, development activities, and research activities. These documents also detail the different milestones and responsibilities to support collaboration among partners and stakeholders.

In March 2007, Secretary of Transportation Mary E. Peters acknowledged that building new runways and implementing new technologies will not be sufficient to meet forecasted demand in the year 2025 and that there was a need for a long-term approach that would include Federal, state and local partners [312]. As an example of such collaboration, the U.S. Department of Transportation along with the Federal Aviation Administration and the MITRE Corporation and Center for Advanced Aviation System Development have conducted different studies to understand where the requirements are and where future capacity constraints are likely to occur. Research has also been focussing on the assessment of demand and capacity levels for both airports and metropolitan areas and the identification of additional capacity needs for the decades to come [314]. The outcome of their work shows that "the predominant trend over the next two decades largely will be the expansion of existing airports to meet forecast demand" [314]. In 2006, the failure to implement NextGen was estimated to cost the U.S. economy 22 billion dollars annually in lost economic activity by 2022 [122, 178].

1.2 *The European Perspective*

The size of the air transportation system in Europe represents about 65 percent of the size of the U.S. system [84]. In fact, while the use of aircraft for private transportation is relatively common in the U.S, there is still very little private air transportation activity in Europe [84]. Nevertheless, similarly to the U.S., the air transportation industry in Europe is an indispensable part of the economic infrastructure, which accounts for about 4.2 million jobs [5] and between 1.4 to 2.5 percent of the European Gross Domestic Product (GDP) [62] (Table 1).

Table 1: European direct and total employment and GDP (2006) (from [5])

	Employment		**GDP (USD million)**	
	Direct	**Total**[1]	**Direct**	**Total**[1]
Airports	156,00	409,500	17,542	46,048
Other on-site airport jobs	308,141	808,869	13,399	35,172
Airlines	748,070	1,963,683	52,724	138,400
Aerospace	313,978	1,020,428	34,349	111,633
Total	**1,526,188**	**4,202,481**	**118,014**	**331,254**

The European air traffic control system is divided up into 26 subsystems consisting of 58 en route control centers, which is approximately three times as many as for a comparable area in the United States. This large partitioning of the European sky can be represented as a network of 100 main European airport "nodes", linked together by approximately 600 airspace sectors operated by more than 36 Air Navigation Service Providers (ANSP) [271]. This diversity and fragmentation, as well as the low level of interoperability, limited information sharing, and lack of integration of the different national air traffic control systems, are limiting factors to air travel growth [297, 113]. Furthermore, the European air transport industry is characterized by an hub-and-spoke operational philosophy, where the airlines are concentrating their operations at a relatively small number of commercial airports. This

[1] incl. direct, indirect & induced

also adds to the congestion phenomena observed at major European airports [242, 297]. Finally, the number of new airport development projects in Europe, as in the U.S, is extremely limited, for various political, social, economical and environmental reasons. All these aspects are contributing to the existing severe congestion and delay problems encountered in the European sky [242, 297].

Similarly to the U.S., air transportation in Europe has seen a continuous and significant increase in traffic (+7.4 percent annually since 1980 in terms of passenger/km) [297, 113]. The hubbing concept, as well as the passengers' demand for more frequent flights, forced the airlines to gradually shift to smaller aircraft [297], resulting in an increase of the number of operations at airports. This upward trend is likely to continue over the next decades. Also, while the en-route Air Traffic Flow Management (ATFM) delay due to growth in air traffic has been decreasing over the last 15 years and seems to be now contained, the air traffic delays at airports, on the other hand, have remained relatively the same [100, 271]. Airports are thus now becoming the major capacity bottleneck and constraint to continued growth in the air traffic management infrastructure [240], with airport delay exceeding en-route delay for the first time in 2006 [100]. However, in comparison to the U.S. practice, Table 2 shows that "European airports enjoy a significant advantage in average aircraft size and serve fewer aircraft operations for a similar number of annual passenger movements" [242].

Table 2: Comparison of the Number of Operations at U.S and European Airports for Similar Number of Passengers (from [242])

Number of passengers	**U.S. Airports**	**Number of operations**	**European Airports**	**Number of operations**
65 million	Los Angeles	783,000	London	467,000
	Dallas/Ft. Worth	838,000	-	-
33 million	Miami	517,000	Madrid	358,000
25 million	Boston	480,000	Munich	315,000

Many airports today are reaching their capacity limits and the European air system, as the American one, is experiencing saturation at some key locations [100]. Back in 2004, it was expected that by 2025 the air traffic in Europe would have grown 2.4 times, resulting in 60 European airports to be congested, and the top 20 airports to be saturated for at least eight to ten hours of the day [111]. Such a scenario would leave European airports unable to satisfy 17.6 percent of the total air transportation demand (about 3.7 million flights per annum) because of capacity constraints [111]. The situation in Europe for the next decades is thus very similar to the one awaiting the American continent.

The European Union recognized the need “to make better use of existing capacity", to “reduce fragmentation between States and harmonize the system in use” [100]. With this in mind, the European Commission generated the Single European Sky (SES) initiative, whose goal is to create a more efficient ATM system to address the issues related to the forecasted traffic growth [100]. According to Jacques Barrot, Vice President of the European Commission, responsible for Transport, “the Single European Sky addresses the need to guarantee safety in the skies and to optimize cost-efficiency of air traffic services, whilst also providing the capacity to avoid delays and to sustain the long-term growth of air transport in Europe” [100]. The European Union is also concurrently working on The Single European Sky ATM Research (SESAR), which is the technological and operational component of the Single European Sky (SES), which should provide all the European ATM stakeholders with “a road map for the implementation of the system until 2020” [100]. More particularly in 2008, EUROCONTROL, which led the Definition Phase of SESAR, released the “*European ATM Master Plan (e-ATM Master Plan)*” [104], and the associated “*Work Programme for 2008-2013*” [106]. This master plan, endorsed by the Council of the European Union in 2009 [64], has been updated and refined in 2010 [17]. It defines the content and establishes the roadmap for the development and deployment of the next generation of ATM systems up to 2020 and beyond. The definition phase of SESAR was completed in 2009 [145], and the development phase (2008-2013) that should provide the required new generation of technological systems and components is in progress. Additionally, to support the coordination efforts of the SESAR development phase, the European Commission and Eurocontrol created the SESAR Joint Undertaking (SJU) [95]. Other strategies and plans, such as the "*ATM 2000+ Strategy*", the "*European Air Traffic Management Program (EATMP)*" or the "*Strategic Guidance in Support of the Execution of the European ATM Master Plan* [108] have been produced over the last 11 years to define and support the development and implementation of the different ATM operational improvements necessary to the realization of a safe, secure and seamless airspace [94, 97, 96].

1.3 A Common Challenge and a Common Goal

Both the U.S. and Europe are competing for global leadership and are trying to address the challenge of satisfying the expected doubling in demand in a safe, secure and environmentally friendly way. Both regions are going to see very few new airport development projects [297, 328], despite the fact that major airports are already experiencing gridlock during peak hours [297]. Additionally, the hubbing concept, in parallel with the desire of the passengers to fly more routes more frequently, are at the origin of the recent downsizing of the major legacy carriers' fleet [297]. Hence, the average number of seat per departure decreased by 12 percent from 1990 to 2000, and by 25 percent between 2001 and 2003 [35]. This, coupled with a higher diversity in the types of airspace users, has resulted in the number of operations growing faster than the passenger traffic [35, 297], which in turn contributes to aggravating the existing congestion issue. Another interesting and common fact is that, over the past 30 years, both passengers and aircraft movements have been funneled into fewer and fewer airports [35, 315, 297]. This non-uniformity of the passenger traffic in both air transportation systems results in most of the available infrastructure being currently underutilized. Finally, in both regions, airport constraints have been identified as being more binding, meaning that the lack of capacity at airports and in the terminal airspace is the major constraint to growth [148, 114]. The characteristics of the problem thus lead to the following observation:

OBSERVATION 1: The forecast demand and resulting capacity issues will have to be addressed with the existing airport infrastructure.

1.4 Potential Solutions

The economic and safety consequences associated with the capacity issue at both European and U.S. airports has forced the air transportation community to actively look at possible solutions to address the mismatch between capacity supply and demand. The solutions that have been proposed in both the U.S. and Europe can be divided into two categories, as described by Zografos [337]: capacity increase strategies and demand management strategies:

- Capacity increase strategies are usually considered from the perspective of airport improvements/developments, airspace procedure improvements, and aircraft improvements [297]:
  - Building new airports and adding new runways at major airports: this is the most effective way to increase capacity but also the most lengthy and expensive one. Further, the implementation of such solutions often faces strong political, environmental and social resistance [337, 297]
  - Implementing new operational concepts improvements and procedures, and deploying advanced technological equipment [337, 297]
- Demand management strategies mainly include limiting the demand or moving it spatially and temporally so that it better matches the available capacity [297]:

- Establishing quotas or temporarily caping flights, as it is the case at Newark Liberty Airport for example, where a cap of an average of 83 flights per hour during peak periods has been agreed upon [248, 337, 297]
- Time-shifting: equate demand and capacity supply by scheduling flights to periods where the demand and thus congestion is lower [248, 337, 297]
- Restricting access by aircraft types or use: this would allow for an homogeneous mix of aircraft types or uses [337, 297]
- Congestion/peak period pricing: airports experience high levels of traffic during peak hours, but operate under capacity for most of the remainder of the time [297]. Some of the solutions proposed to address this point include increasing fares or implementing policies on landing fees. This would allow airports to use pricing to spread traffic more evenly throughout the day [248, 337, 297, 170, 244], hence better matching demand to the available (and limited) supply of airport capacity. Such strategy is particularly valuable for airports that have limited capacity expansion options [123].
- Spatial shifting: facilitating traffic management and reducing congestion by moving or diverting flights from busy and congested airports to neighboring, less used, secondary and regional airports [248, 337, 297, 123, 244]

As acknowledged by Forsyth [130], adding to airport capacity is difficult and permission to do so is often refused, mainly for environmental reasons. In the case where such permission is granted, large complex runway projects or capacity increase projects on constrained sites still required long lead times and a considerable amount of money (illustrative examples in Europe include the Terminal 5 of London Heathrow Airport [43] and Frankfurt Main Airport) [314, 130, 250, 170]. In some cases, such as for the San Francisco Bay area, runway construction is simply not an option [295]. The implementation of new technologies and operational concepts at both the airport and the airspace levels also requires some amount of time in training and implementation. It is therefore necessary to act as soon as possible to avoid an increasing number of airports experiencing capacity shortages.

There are divergent opinions with regard to the capability of new technologies and operational concepts to resolve the congestion issue. NASA for example stated that "new technologies and operational concepts, nearly in hand and in early development, offer the potential to far surpass those constraints and create a new level of performance and capability in aviation" [151]. While others argue that "even the most optimistic studies indicate that the number of new runways projected to be built and the new technology that may be deployed will fall significantly short of accommodating projected demand" [86]. SESAR and the THENA Consortium, for example, noted that, while operational improvements may provide up to 20 percent additional capacity (primarily by unlocking latent peak hour capacity), they are rather site specific and only offer a short-term answer to the capacity issue. As such, they will not significantly relieve congestion at major airports [297, 272]. Similarly, the U.S. Government Accountability Office [310] recognizes that "NextGen alone is not likely to sufficiently expand the safety and capacity of the national airspace system". In particular, the results from the FACT 1 and 2 studies reveal that, even when the planned improvements (including implementing capacity-related operational concepts) are completed, certain hub airports and surrounding metropolitan areas will still experience unacceptable levels of delays by 2013 and 2020 (Figure 5) [314, 295]. Along the same line, research conducted by Hunter [158] using the Airspace Concepts Evaluation System (ACES) simulation tool shows that the anticipated National Airspace System (NAS) capacity improvements from OEP investments are not sufficient to accommodate 2X and 3X levels of traffic: "These demand scenarios quickly outstrip current and anticipated NAS capacities, resulting in unacceptable levels of delay or flight cancellations. ACES simulations show that at higher levels of demand, system delays quickly rise over the course of the simulated day to untenable levels. Simply put, it is not possible to operate a scheduled air transportation system in such a congested and unreliable environment, nor are passengers likely to be willing to make use of such a system." Similarly, Eurocontrol [111], in "*The Challenges to Growth*" study published in December 2004, reported that even if they use every runway to its maximum capacity, "airports will be unable to cope with the demand if traffic continues to increase in line with the higher estimates of future growth." In the same document, 80 percent of the airport operators interviewed stated that physical site and infrastructure limits, as well as environmental and physical constraints, would prevent them from achieving the capacity of the best performing airports.

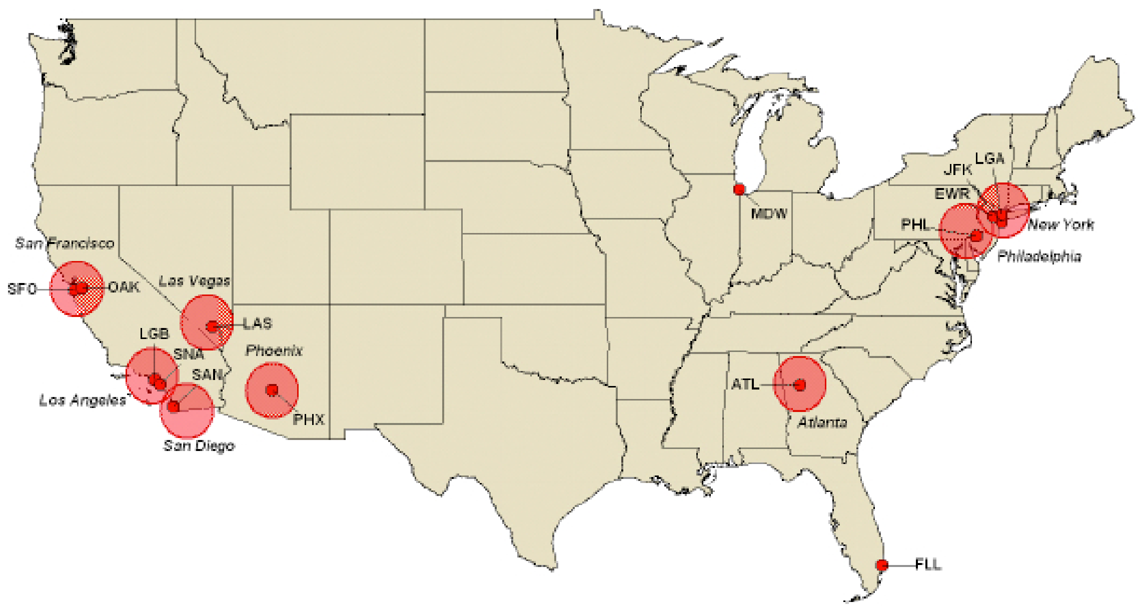


Figure 5: Airports and metropolitan areas needing capacity in 2025 after planned improvements (from [295]).

There are also concerns with regard to the financing of the new capacity enhancing technologies. In the U.S., "the Government Accountability Office estimates that the FAA will have a cumulative $4-billion operating deficit by 2010" [86]. In general, most experts emphasize that the solution will come from a significant transformation of the air system and call for the development of air system architecture transformation strategies that will meet system performance requirements in areas such as noise, emissions, safety and security [158]. Many authors have also emphasized the fact that there is not one single unique solution to the current capacity issue and that it would be a mistake to focus only on capacity increase strategies [125, 118]. As mentioned by the FAA, it is essential to consider solutions such as “new runways, new airports, regional emphasis, congestion management, multi-modal planning, and NextGen” [295]. Hunter also emphasized the need to appraise the economic value of each combination of solutions [158]. This leads to the following observation:

OBSERVATION 2: Addressing the capacity issue will require the consideration and implementation of a combination of solutions and strategies, which would need to be evaluated with economic impacts in mind.

Figure 6 provides an evaluation of the seven solutions mentioned in Section 1.4 with respect to the challenges faced by the air transportation industry as identified in Section 1.3. From this Figure, it appears that moving or diverting flights from busy and congested airports to neighboring, less used, secondary and regional airports would contribute to addressing all the aforementioned challenges. The following section proposes to look at the case of underutilized and secondary airports into more detail.

S1	S2	S3	S4	S5	S6	S7	
✗	✓	✓	✓	✓	✓	✓	**Does not require new infrastructure development**
✓	✓	✓	✓	✓	✓	✓	**Help reduce gridlock at major airports during peak hours**
✓	✓	–	–	–	–	✓	**Help absorb the increase in number of operations**
✓	–	–	–	–	–	✓	**Help reduce the non-uniformity of passenger traffic**

With:

S1: Build new airports, and add new runways at major airports
S2: Implement new operational concepts and procedures, and deploy advanced technologies
S3: Establish quotas or temporarily cap flights
S4: Time-shifting
S5: Restrict access by aircraft types or use
S6: Congestion/peak period pricing
S7: Spatial shifting

Figure 6: Evaluation of the proposed solutions with respect to the challenges faced by the air transportation industry.

1.5 The Call for the Use of Underutilized and Secondary Airports

The development and use of underutilized and secondary airports is receiving more and more support from the air transportation community and industry stakeholders [35, 36, 158, 295, 155, 208, 309, 310, 123]. Indeed, many have identified the development and increase of operations at smaller, underutilized airports as a key means to alleviate congestion at primary airports and help meet travel demand particularly in metropolitan areas that experience high levels of traffic. Malik et al. [208], for example, mention that “optimizing the use of current airport infrastructure through innovative concepts, technologies and procedures is desirable.” In the same vein, Forsyth [130] states that “the increased use of secondary airports, along with spare capacity at major airports, does help solve the airport capacity problem in the short term." The NGATS Report also mentions that “it is essential to enable increased operations at smaller airports in the same region to offload some of the demand on the busiest airport(s) where practical (e.g. air taxi operations)" [289]. In the same report, it is acknowledged that "significant growth at the busiest airports as well as regional and smaller airports is needed to achieve the capacity goal of the NGATS" [289]. In its Report to Congress, the FAA also points out that "redistribution of traffic among airports to make more efficient use of facilities is another measure that can be used to reduce delays" [315]. In that same report, the FAA stresses that "another factor that helps to limit delay is the ability of carriers to introduce service to outlying, suburban airports, using them to relieve congestion at the principal airport" [315]. The THENA Consortium also recognized that "new secondary airports that are adjacent to main population areas might constitute an additional air traffic channel (with even more rapid growth rates than the hub), especially for short haul, point-to-point routes" [297]. The academic world has also recently demonstrated an interest in secondary airports, as illustrated by the work of Bonnefoy and Hansman [35, 36], and de Neufville and Odoni [72]. Additionally to the research community, some governments are now more interested in developing secondary airports, as illustrated by the British government who refused to expand London Heathrow but gave the priority to the expansion of Stansted airport, the London metropolitan region secondary airport [130]. Major congested airports, such as Newark (EWR) or La Guardia (LGA), are also now starting to consider an increase in the number of operations at regional airports, as well as the effect that the expansion of these airports may have on delay reduction, when planning for their additional capacity enhancements [295]. Then, as shown by Bonnefoy [35], secondary airports also offer a cost advantage to airlines operating from this type of airports. Finally, the growing interest for secondary airports comes from the travelers themselves. More and more travelers are flying from alternate or secondary airports and are motivating their choice by citing reasonable driving time, ease of access, competitive air fares and time savings [92, 131]. Also, as noted by Bonnefoy, the popularity of secondary airports can further be illustrated through most of air travel ticket reservation websites, which now provide flight availability to or from airports located 50 or 70 miles away from a major airport [35].

Secondary airports now represent a viable alternative for accessing metropolitan areas [35]. As a matter of fact, mid-size airports located in congested metropolitan areas such as Los Angeles or New-York City are the fastest-growing airports in the U.S [131], with a rate of growth which represents up to three times the rate of growth at other U.S airports [311]. This growth has been particularly significant in the past decade, with passenger and traffic volumes increasing by up to 400 percent at certain airports. Long Island MacArthur Airport located some 75 minutes from Manhattan for example, has seen its number of departing passengers increase from 240,000 to 1.2 million between 1998 and 2007. Similarly, passenger traffic at Manchester Boston Regional Airport quadrupled from 500,332 passengers in 1996 to 1.85 million passengers in 2002, while passengers leaving from Logan declined by about 10 percent, to 11 million, during that same timeframe [92]. Some airports have seen an even more dramatic increase in passenger traffic. For example, Steward International Airport, located about 60 miles north of New-York City, has tripled its passenger traffic in 2007 alone [249]. This trend has also been observed at other airports such as Baltimore-Washington International Marshall Airport [216], Fort Lauderdale or Midway [92], confirming that this type of airport offers a viable option to air travel. The growing interest for secondary airports, which is particularly related to the arrival of low cost carriers [216, 131, 249, 307, 72], is also very strong in Europe. Thus, Brussels South Charleroi airport saw its passenger traffic increase from 200,000 travelers to more than 2 million annually in only four years, due mainly to the presence of two of the busiest low-cost airlines [307]. Table 3 summarizes the increase in passenger traffic experienced by some airports in the United Kingdom.

While the emergence of secondary and regional airports presents a strong interest for the problem at hand and is likely to strengthen [35], these airports will eventually reach their capacity limit at some point in the future, and will be required to invest in equipment

Table 3: Growth in traffic at secondary airports served by low-cost carriers (from [78])

Metropolitan region	Airport	Passenger traffic in 1995 (million)	Passenger traffic in 2002 (million)	Growth (%)
London	Stansted	2.9	14.8	405
London	Luton	0.6	5.4	873
Manchester (UK)	Liverpool	0.4	2.4	551
Glasgow	Prestwick	0.2	1.3	508

and technology to help increase their number of operations and/or sustain their growth. However, developing underutilized and secondary airports is a challenging undertaking. One of the challenges associated with airport capacity-enhancement planning is timing, i.e. the necessity to synchronize evolving technologies with airports' needs and investment capabilities [180]. Thus, as airports are developing their capital plans, it is primordial that their stakeholders fully understand the impacts, implications, and challenges current and future technology improvements will bring to airports [136]. This leads us to the following assertion:

ASSERTION 1: Developing underutilized and secondary airports requires that the benefits and impacts of technologies be recognized and incorporated into the airports' capital plans.

As discussed in Section 1.5, the evolution of secondary airports, and their needs, are tightly linked to their environment. Hence, while assessing the benefits and impacts of technologies is necessary, it is essential that the factors that drive the need for technology acquisition be also investigated and that the main factors that influence the environment airports operate in be identified. This last aspect is discussed in the following Section.

1.6 A Changing Environment

Air transportation is a continuously evolving industry. The changes that this industry has seen over the years are due to the various interacting factors that influence it. These, as mentioned in the literature [55, 196, 287, 203, 32, 35, 143, 222, 224, 225, 209, 211, 133] are listed and detailed below, starting with the ones pertaining to the airport's environment:

- Demand growth: demand growth has a direct impact on the mix and number of operations that an airport sees, and thus on the revenues generated from them

- Mergers in the airline industry and hub restructuring: As airlines merge, routes and services to airports are being canceled thus resulting in lost of operations and revenues for concerned airports. Similarly hub restructuring may result in an airline shifting its base of operation from one airport to another, which can result in dramatic consequences for airports depending solely on a single carrier. Pittsburg International Airport was a prime example of this situation [144]

- Changes in government policy and regulations: new policies may necessitate new infrastructure to comply with noise abatements measures, for exmaple. New regulations can affect the airports' options and sources of funding as well as their financing methods and schemes

- Competing technologies and modes of transportation: in some regions, airports must compete for travelers with other modes of transportation such as high-speed rail or highways. New technologies such as videoconferencing or internet communications have also reduced the need for people to fly to business meetings

- Fluctuating fuel prices: Increases in fuel prices impact ticket prices and thus the financial ability to travel

- Deregulation and Privatization: As pointed out by de Neufville and Barber [73], economic deregulation by removing "barriers to changes in prices, frequency of service, and routes, increasses the volatility of traffic. Hence, deregulation and privatization can be at the origin of new types of customers, requirements and airport networks as witnessed by the development of Low Cost Carriers or business jets

- Development of new and revolutionary vehicles: with new vehicles comes new requirements. As an example, the A380 requires longer and larger runways, new gate design, reinforced taxiways, and so on

- Increased airport/airline competition: congestion at one airport may result in a shift in traffic [74]. As a matter of fact, airlines will be more likely to operate from airports having less congested facilities [74]

- Fluctuations in local and global economies: airports located in regions with declining economies may be affected by a decrease in tourists or business travelers, while those located in booming or wealthy regions will be more likely to attract more passengers.

- Changes in the type of customers and passengers: the expectations in terms of infrastructure for Low Cost Carriers and National Carriers are different. Low-cost carriers have also shown that they can significantly impact airport success, as illustrated by Baltimore's Washington International Airport (BWI), which, after attracting AirTran, became the region's second busiest airport in 2006 [55]. Along these lines, Bonnefoy also noted that the entry of low-cost carriers was the most important factor in the emergence of secondary airports [35]

- Wars, crises, catastrophes and pandemics: Economic recessions, 9/11 attacks, or the SARS outbreak, have had significant detrimental consequences on the airline industry (Figure 7) and thus airport revenues

- Public support: Public support to a conveniently located airport can have negative effects on a less centrally located neighboring airport. Public support, in some cases, also prevented the closure of airports, as it was the case, for example, at Kansai International Airport (KANSAI) and Osaka International Airport (ITAMI)

- Availability and performance of necessary equipment and technology: airport growth and increase in revenues are also dependent on the availability and performance of needed technology and equipment. Technologies not being available or not performing as expected may result in airports missing opportunities to increase their traffic and thus revenues

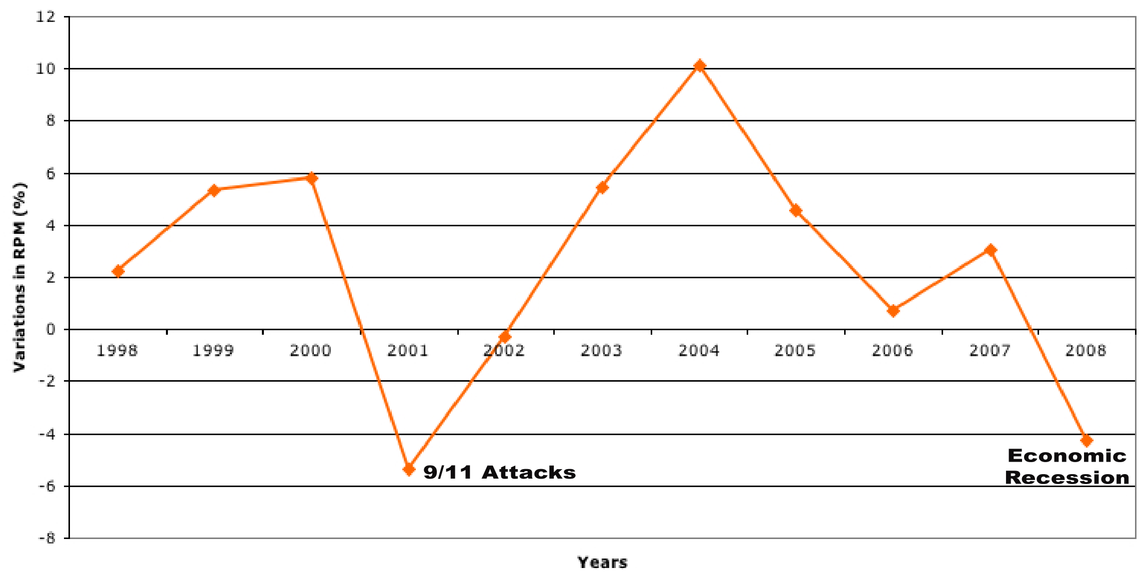


Figure 7: Growth Rate in the U.S. Domestic Market (expressed in terms of revenue-passenger miles (RPMs) for the years 1998 to 2008. (Source: [46])

As previously mentioned, the Air Transportation industry is particularly sensitive to changes in its environment. In particular, it is well-known for undergoing periods of high growth followed by periods of significant traffic decrease [275, 285]. This cyclic behavior can be illustrated by looking at the demand for air transportation, measured in terms of revenue-passenger miles (RPMs) (Figure 7). The demand dropped in 2001, after experiencing a strong growth throughout the 90's, and then steadily grew following 2001 to plummet again from 2004 to 2006, and later in 2008. However, changes in the industry, while having a strong impact on airport survivability, are often unpredictable: previous studies have shown that long term forecasts are generally at least 20 percent off from reality [241]. Some changes also have more important effects than others. Hence, the air transportation industry tends to be particularly sensitive to changes in regional economic health [55]. Secondary airports have also often challenged previsions on traffic development [55] and the disparities between projected and actual traffic or demand have had disastrous consequences on the airports' profitability and viability. Montréal/Mirabel, for example, once the second largest airport in the World in terms of surface area, failed to attract the 20 million passengers expected annually (it only captured less than 3 million passengers per year [70]), and is now used almost exclusively for cargo flights [329]. Additionally, in many occasions in the past, secondary airports worldwide were built prematurely [72]. For example, Washington/Dulles, originally expected to surpass Washington/Reagan, has suffered from poor planning and remained largely underutilized for its first 20 years [70, 72]. Similarly, Stansted, while having experienced significant traffic growth over the last decade, is still largely underutilized with concourses deserted most of the time [72].

Other factors exist that have a strong influence on the availability and performance of technologies in particular, and the level of airports operability and service as a whole. These factors are described below [27, 153]:

- New uses: the implementation of a new technology may require the acceptance of new procedures, requirements, or systems which users may be reluctant to follow or adopt at first [168]
- Innovativeness: the more innovative the technology, the more uncertainty associated with it
- Number of constituent technologies: the more a technology depends on other technology, the more difficult it is to assess its overall performance
- Institutional changes: sometimes institutional or policy changes are required for a technology to achieve useful deployment

- System upgrades: a system upgrade can have an impact of the performance of a technology and may require an additional capital outlay [153]

As mentioned above, the air transportation industry is a highly complex system characterized by continuous changes. In particular, the industry's sensitivity to these changes and their dramatic consequences on airports' viability, and profitability, as illustrated by the recent airport planing failures, bring us to the following assertion:

ASSERTION 2: The development of secondary and underutilized airports will be successful if the impact of changes on the system can be captured

Most of the failures attributed to airport planning and development, as illustrated in Section 1.6, have mainly resulted in two situations: [183]:

- "overbuild": the forecasted demand and traffic does not materialize and the infrastructure remains underutilized
- "underbuild": the infrastructure is inadequate to accommodate an unforeseen growth or change in demand and traffic

As previously discussed, the air transportation industry is highly sensitive to changes in its environment. Hence, investment decisions that may carry little risk at one time, may be considered highly risky as the future unfolds [167]. In other words, "the risk-pattern" of any investment project is likely to change over time [39]. Risk, previously defined by Twiss [306] as "the penalty which could arise from a different outcome from that on which a decision was based", is a consequence of uncertainty. Assessing risk is an arduous task, as risk can be easily misevaluated, particularly for new technologies [255]. One way to mitigate risk is to provide decision-makers with the capability to adapt. As emphasized by Smit and Trigeorgis [276], "adapting to, or creating, changes in the industry or in technology is crucial for success in dynamic industries". In particular, past studies have shown that such capability can lead to increase project value and opportunities for success [228, 166]. Previous work on system design and infrastructure development, for example, has recognized [74, 70, 223, 222, 264] and assessed [55, 212] the benefits and value of considering alternate strategies at each stage of project development. From a technology investment perspective, decision-makers should thus be provided with the capability to review and adapt their strategy and technology portfolio as the future unfolds. As a matter of fact, it may be possible that adding a technology to an already existing portfolio may bring more value to the customer, than if that technology was included in the portfolio definition in the first place, and this even if the price to be paid is higher. In other words, the definition of technology portfolios should account for changes in external factors, but should also consider investment decisions previously made, as well as resources already present and available. This bring us to the last assertion of this chapter:

ASSERTION 3: Incorporating and maintaining the capability to adapt to continuing changes when planning for the development and expansion of secondary and currently underutilized airports is essential to ensure the financial sustainability of their investment decisions

1.7 Summary

This present chapter first provided a brief overview the air transportation industry from both a U.S. and European perspective. In particular, the discussion regarding the challenges faced by this industry led us to recognize that the forecasted demand and capacity issues resulting from the expected growth in air traffic will have to be addressed within the existing airport infrastructure. This observation (see Observation 1) constitutes the first focus item of this research:

Research Focus 1: This research focuses on existing airport infrastructure only.

Following this observation, a careful examination of the solutions proposed to address the forecasted demand and resulting capacity issues was conducted. It led to the realization that such issues could only be tackled by considering and implementing a combination of solutions and strategies (see Observation 2). This observation, along with the evaluation of proposed solutions with respect to the air transportation challenges, constitutes the second focus of this research:

Research Focus 2: This research focuses on the implementation and deployment of new operational concepts and advanced technologies at secondary/regional airports.

In this respect, the interest and support expressed by the air transportation community to develop underutilized and secondary airports was discussed. Additionally, the challenges associated with sustaining the development of these airports were mentioned. In particular, the need to synchronize evolving technologies with airports' needs and investment capabilities was recognized, and led to the first assertion:

Assertion 1: Developing underutilized and secondary airports requires that the benefits and impacts of technologies be recognized and incorporated into the airports' capital plans.

The realization that the evolution of secondary airports, and their needs, are tightly linked to their environment prompted a review of the various forces and sources of uncertainty impacting the airport environment. The sensitivity of airports to changes in the dynamics of their environment, as illustrated in Section 1.6, requires that the factors that drive the need for technology acquisition be identified. In this respect, the following assertion was made:

Assertion 2: The development of secondary and underutilized airports will be successful if the impact of changes on the system can be captured.

Finally, the difficulty to evaluate risk and make financially viable decisions, particularly when investing in new technologies, was recognized. The capability to adapt to evolving circumstances as a way to mitigate risk and address uncertainty was proposed and its benefits were discussed. From there, the last assertion was formulated:

Assertion 3: Incorporating and maintaining the capability to adapt to continuing changes when planning for the development and expansion of secondary and currently underutilized airports is essential to ensure the financial sustainability of their investment decisions.

1.8 Dissertation Content and Structure

This present chapter, through the formulation of observations and assertions, motivates the need for this research, and defines and delimits its scope. The following chapter reviews and discusses the state-of-the-art, as well as the various aspects pertaining to each of the assertions formulated in Chapter 1. Pertinent research questions and hypotheses are then formulated based upon the challenges and shortcomings identified. Next, Chapter 3 briefly introduces the approach developed to address these Research Questions and validate each of their associated Hypotheses. Chapters 4, 5, 6 and 7 discuss in more detail the development and implementation of the specific steps of the proposed approach. Chapter 8 summarizes the findings of this research. Finally, Chapter 9, review the challenges, limitations and contributions of this work.

CHAPTER II

PROBLEM DEFINITION

“I have yet to see any problem, however complicated, which, when looked at in the right way, did not become still more complicated”

- Poul Anderson

This present chapter discusses in more details the different aspects and challenges associated with each of the assertions made in the first chapter. Hence, this chapter follows a structure similar to Chapter 1 and begins by addressing the first assertion.

ASSERTION 1: Developing underutilized and secondary airports requires that the benefits and impacts of technologies be recognized and incorporated into the airports’ capital plans.

2.1 Introduction

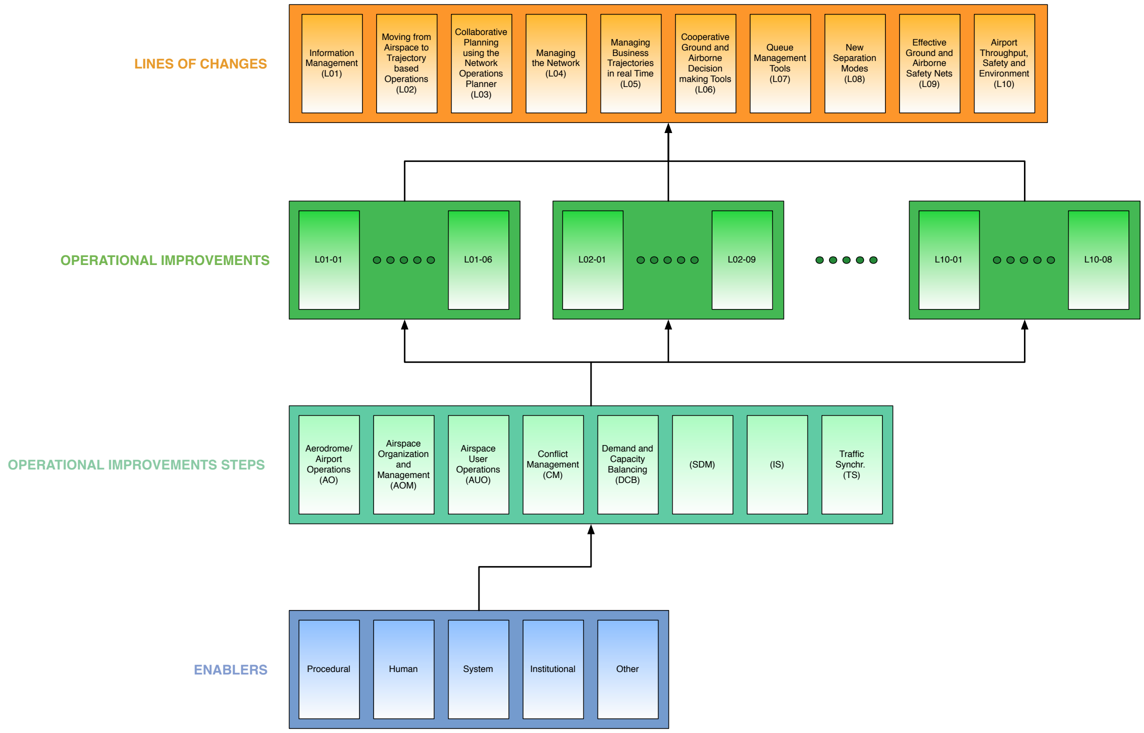
Technology comes from the Greek *Tekhnologia*, meaning the systematic treatment of an art or craft [44]. In the Greek mythology, *Tecnh* or *Tekhnê* was the spirit of art, technical skill and craft [298]. Diverse definitions of technology exist in the literature. Porter, for example, refers to technology as “the systematized knowledge applied to alter, control, or order elements of our physical or social environment" [255], while Twiss defines it as “the application of scientific knowledge for the satisfaction of human needs" [306]. However, independently of the definition chosen, there exists a general consensus that new technologies are being developed to answer a need, fill a gap (market pull) or yield future benefits, rather than for the sake of innovation (technology push) [27, 306]. As mentioned by Twiss

[306], technology is a means, that only advances because of investment in it that results from the perception of a need.

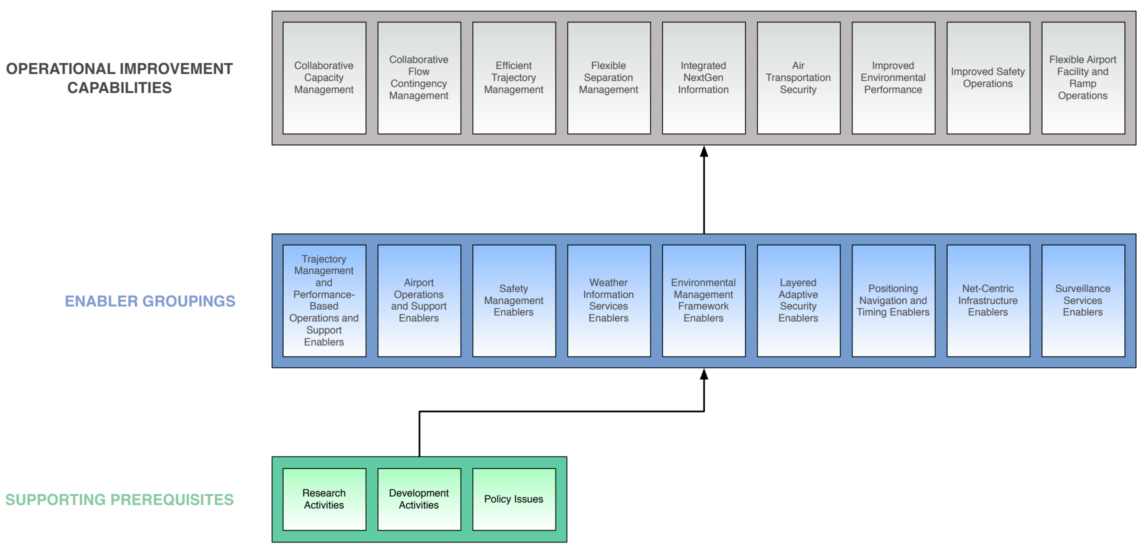
The Air Transportation industry has reached a peak with existing technologies having achieved maturity. Because the industry growth cannot be sustained indefinitely with existing technologies, new technologies and operational concepts are being developed and tested to help meet the industry's future needs.

As discussed in Chapter 1, both the United States and the European Union have been working to address the challenge of satisfying the expected increase in demand in a flexible, safe, secure and environmental friendly way [50]. In the United States, the JPDO has established and released updated iterations of the "*Enterprise Architecture Version*" to the NextGen Joint Planning Environment (JPE) [176, 182]. It has also published revised versions of the "*Next Generation Air Transportation System Integrated Work Plan (IWP)*" [180, 175], which provides information on the operational improvements, enablers, policy issues, development activities, as well as research activities, that should help address the industry challenges. On the European side, Eurocontrol released the "*European ATM Master Plan (e-ATM Master Plan)*" [104], and the associated "*Work Programme for 2008-2013*" [106], which define the content and establish the roadmap for the development and deployment of the next generation of ATM systems up to 2020 and beyond. This plan has been further refined and updated in 2010 [17].

The integration schemes for both SESAR and NextGen (Figures 8(a) and 8(b)), while somewhat different, give a first idea of the level of interdependencies and interrelationships that exist between each of the constituents of these architectures.



(a) Simplified representation of the e−ATM master plan components.



(b) Simplified representation of NextGen integrated work plan.

Figure 8: More detailed representations of both structures.

As illustrated in Figure 8, lines of changes are formed by different Operational Improvements that may be related to one another. These Operational Improvements are themselves dependent on various Enablers, themselves supported by different Technologies, which are also, in most cases, interdependent. Several Enablers (and thus Technologies) may be required to define one given Enabler, that may, in turn, be necessary to support different Operational Improvements (Figure 9).

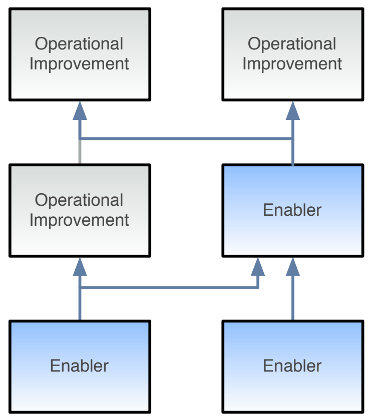
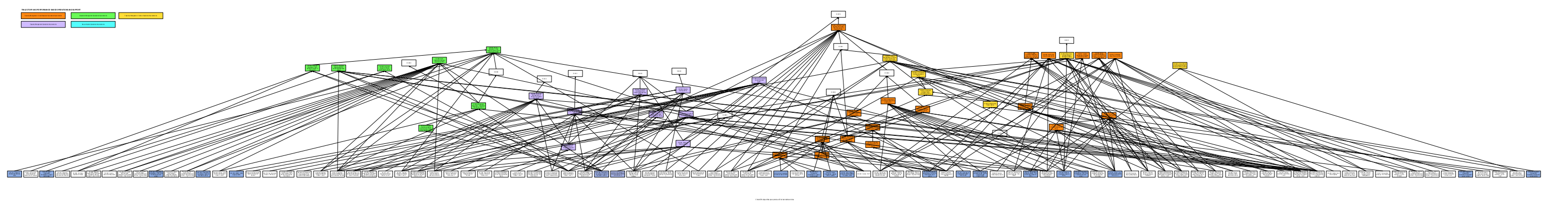
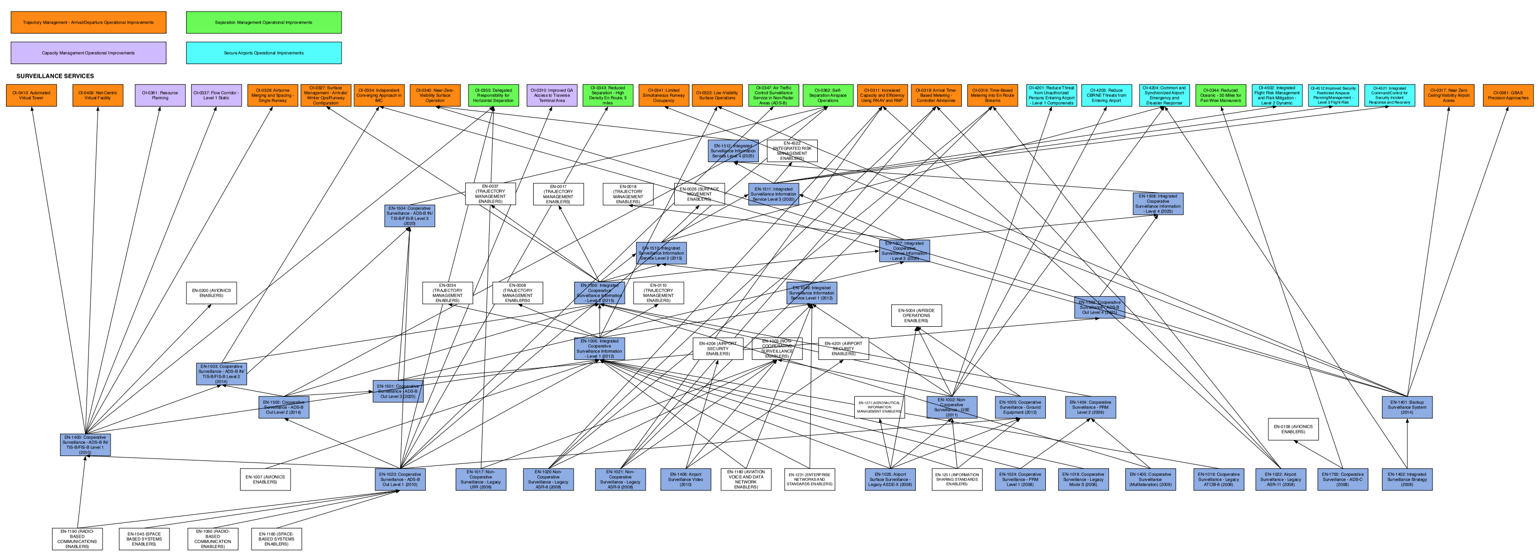


Figure 9: Example of possible relationships between enablers and operational improvements.

Figures 10(a) and 10(b) present the mappings for the "Trajectory Management and Performance-Based Operations and Support Area", and the "Surveillance Service Area", hence illustrating the relationships between different Operational Improvements and their Enablers. These figures exhibit particularly well the high level of interdependency between the elements. These mappings were realized based on information gathered from the study of the "*Next Generation Air Transportation System Integrated Work Plan (IWP) Version 1.0*" [180]. Additional descriptions of the different Functional Groups, Operational Improvements, and Enablers can also be found on the NextGen Joint Planning Environment (JPE) website [176].



(a) For the trajectory management and performance-based operations and support group.



(b) For the surveillance services group.

Figure 10: Mapping for two different functional areas/groups.

As airports face technological needs, they're going to look for answers among existing but also future technologies. Hence, it is essential to relate the information provided by both NextGen and SESAR to the airport's present and future needs. However, determining which technologies or operational concepts could answer these needs is a challenging task mainly because of the aforementioned interacting, interrelated and interdependent relationships that exist between the different current and future technological options. As such, a multitude of combinations of operational concepts and technologies can be investigated and selected that could potentially satisfy the airport's future requirements. Moreover, as new technologies become more mature over the next coming years, it will be necessary for the decision-maker to familiarize himself with the future options that will become available to him. This brings us to the following Research Question:

Research Question 1: How do we provide the decision-maker with a rigorous, structured, traceable and comprehensible process for technology selection?

This question is one of the cornerstones of this research. However, at this time, its formulation is too generic for it to be offered a valuable answer. The following paragraphs discuss the different aspects encompassed in this question in an attempt to formulate sub-Research Questions for which hypotheses can be proposed and tested.

Given the nature of the relationships between each constituent of NextGen and SESAR's structure, it appears evident that decomposing the problem first is necessary to better capture the many features proposed by these two programs. This decomposition needs to be airport-independent as there are no two identical airports. It also needs to be program-independent, given the fact that equipment/technology manufacturers, in both the U.S. and Europe, need to be able to compete and provide for both air systems. This leads us to the following sub-Research Question:

Research Question 1.1: Which decomposition technique(s) should be implemented to provide the decision-maker with a rigorous, structured, and traceable process for technology selection?

Investigating interrelationships between technologies is also crucial when making investment decisions, as technologies impact each other. As mentioned by Jeong and Kim, "in most cases, strategic decision makers cannot find the key technology they should fund without considering the interrelationships between technologies" [172]. Thus, once the problem decomposition is completed, the key technology(ies), meaning the one(s) with a strong technological causality, need to be identified. This brings us to the next sub-Research Question:

Research Question 1.2: Given the decomposition proposed and the nature of the relationships between each of its constituents, how do we determine the causal impact between technologies and identify the nature of their relationships?

Finally, the impact of selected technologies on the performance of the system needs to be assessed to ensure that these technologies properly address the airport needs. However, as previously discussed, most of these technologies are interdependent, and currently under-development. This point leads to the following sub-Research Question:

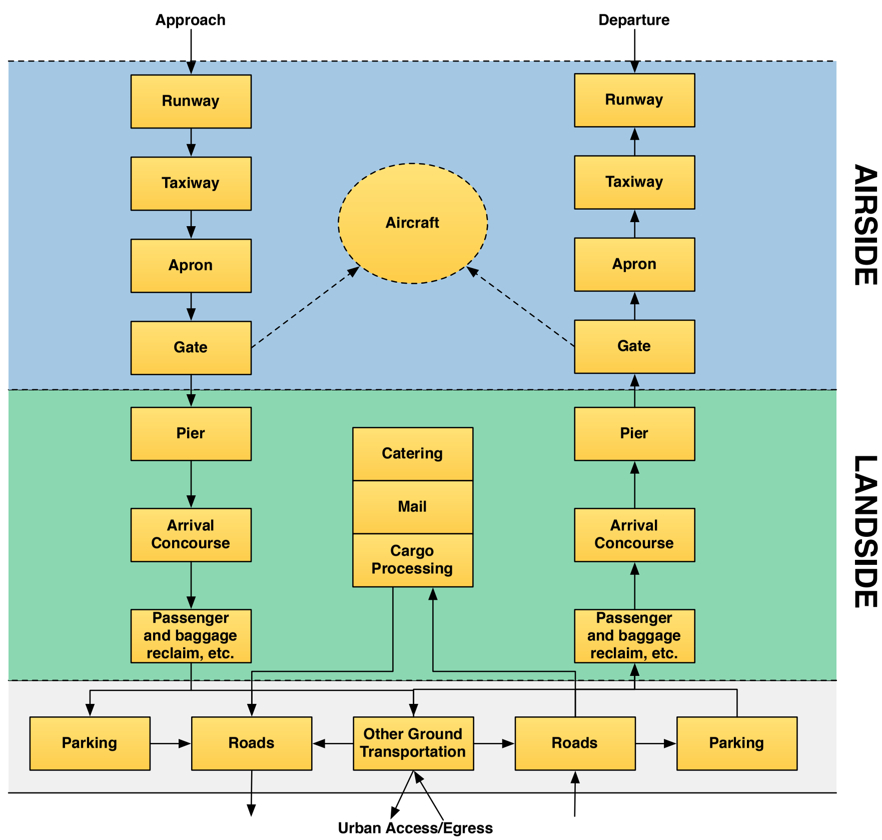
Research Question 1.3: How can the impact of a portfolio of technologies be evaluated given the interdependent nature of most of its technologies and the uncertainty that shrouds their performance?

The following sections discuss each of the aforementioned assertions and provide preliminary Hypotheses to each of the sub-research questions formulated above.

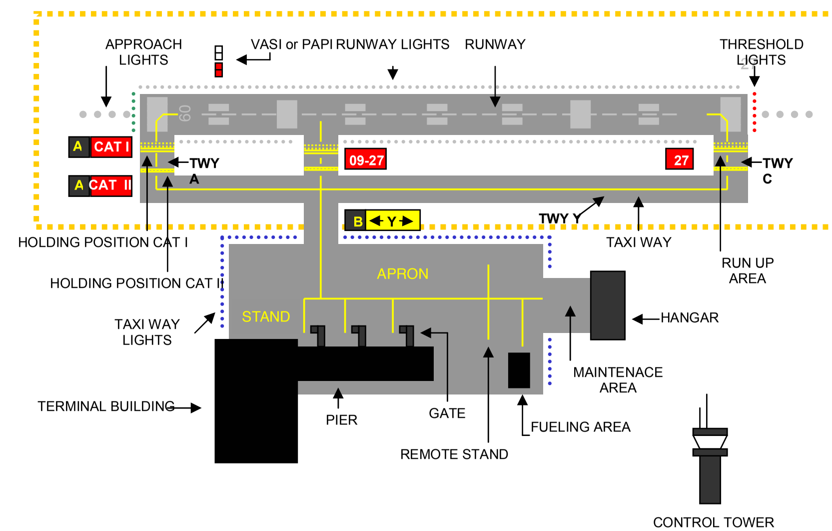
2.2 Problem Decomposition

Before attempting to decompose the problem, it is necessary to take a step back and understand what is the problem or system which needs to be decomposed.

Airports are often referred to as "systems". A system, as defined in the "*Systems Engineering Handbook*", is "a combination of interacting elements organized to achieve one or more stated purposes" [165]. Airport operations, and thus functions, are often divided between landside and airside functions, as illustrated in Figure 11(a). Figure 11(b) provides a definition and illustration of particular terms of interest.



(**a**) The airport system (from [16]).



Orange dotted area = Maneuvering area

Apron: Area used for aircraft loading or unloading of passengers, mail or cargo, fueling, parking or maintenance
Maneuvering area: Part of an aerodrome intended for the take-off, landing, and taxiing of aircraft, excluding aprons
Movement Area: Area consisting of the maneuvering area and apron(s)
Stand: Designated area on an apron for aircraft parking

(**b**) Typical airport layout (from [320] and [163]).

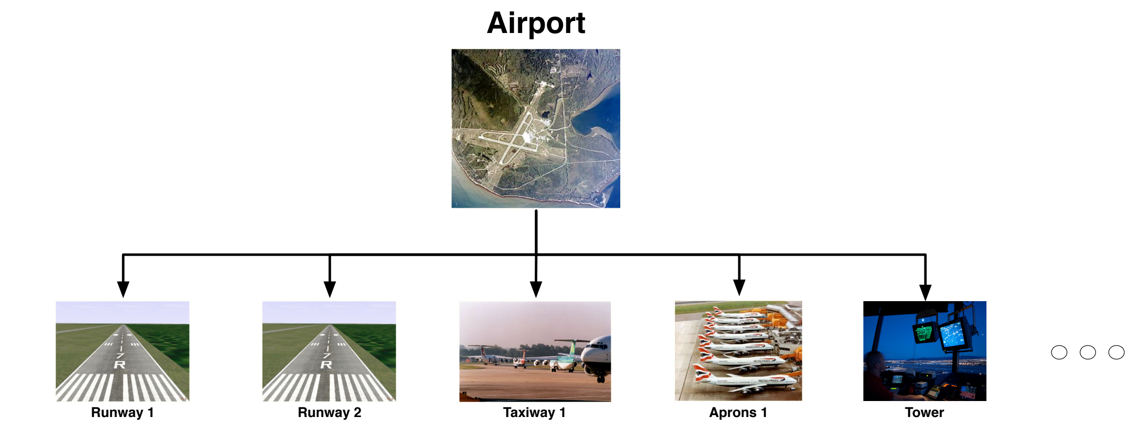
Figure 11: Airport system and typical layout.

The goal of the decomposition is to support the down-selection of relevant technologies based on airport needs. A review of decomposition methods and techniques that could be of interest for the system under study is provided below.

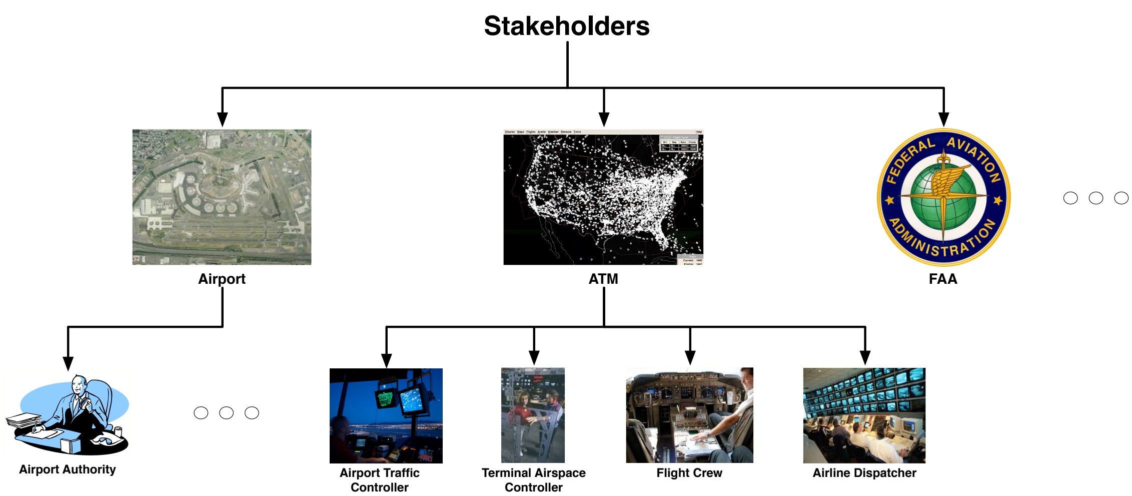
As previously mentioned, the huge combinatorial space represented by the multitude of Operational Improvements and Technologies requires the decomposition of the system into manageable states. However, in order to provide the decision-maker with a rigorous, structured, and traceable process for technology selection, the type of decomposition chosen should:

- Support the future evaluation of the performance of the system
- Support the assessment of the impact of technologies and operational concepts on the system functionality
- Allow for the inclusion of revolutionary operational concepts and technologies
- Not be restricted to a particular airport
- Not be restricted to a particular program (either SESAR or NextGen)

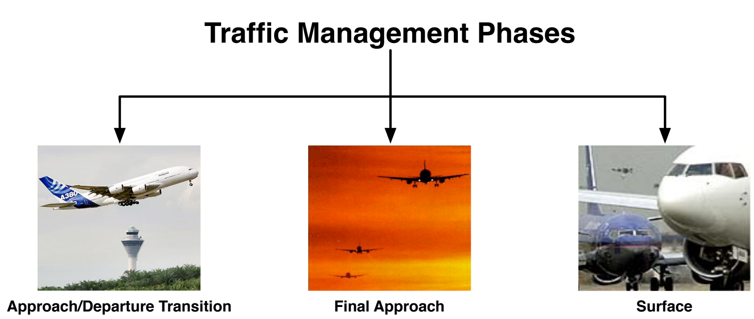
Figure 12 illustrates three possible types of decomposition: physical decomposition (Figure 12(a)), stakeholder-based decomposition (Figure 12(b)), and functional decomposition (Figure 12(c)).



(a) Physical decomposition.



(b) Stakeholder-based decomposition.



(c) Functional decomposition.

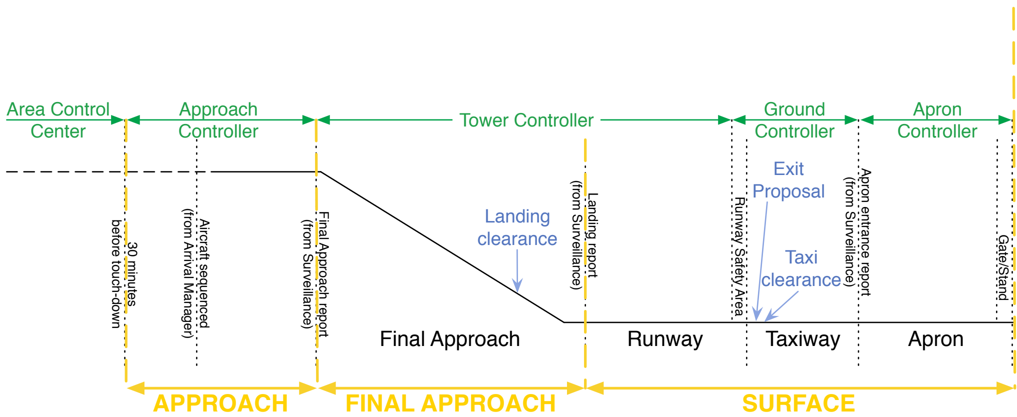
Figure 12: Possible types of airport system decomposition.

As illustrated in Figure 13, a functional decomposition is very likely to be the most suitable for the system considered.

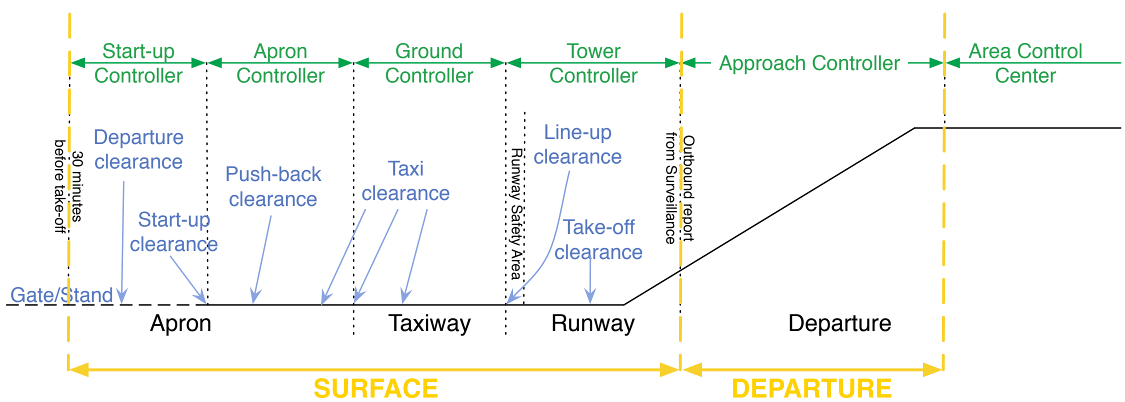
Physical Decomposition	Stakeholder-Based Decomposition	Functional Decompostion	
✓	✓	✓	Support the future evaluation of the performance of the system
X	X	✓	Support the assessment of the impact of technologies and operational concepts on the system functionality
X	X	✓	Allow for the inclusion of revolutionary operational concepts and technologies
X	X	✓	Not be restricted to a particular airport
✓	X	✓	Not be restricted to a particular program (either SESAR or NextGen)

Figure 13: Comparison of the three types of decomposition.

Functional decomposition is a technique widely used in systems engineering, which consists in grouping entities with respect to the task they fulfill. Selecting this type of decomposition also makes sense because technologies and operational concepts are often defined in terms of the function they perform. The functional decomposition proposed, one by traffic management phase, as already received some consideration in the past. As mentioned by Haraldsdottir et al. and Bradford et al., breaking down the system into a series of interacting traffic management phases makes it easier to assess the problem and potential solutions, and measure the efficiency of the implementation of new concepts and technologies [40, 147]. This decomposition has also for advantage that it is applicable to any airport in the world. Finally, because most of the capacity issue is concentrated at the terminal area level, this work focuses only on the “Approach/Departure Transition”, the “Final Approach”, and the “Surface” phases. Figure 14 illustrates these traffic management phases in the context of the Air Traffic Management (ATM) actors and airside infrastructure.



(a) Inbound.



(b) Outbound.

Figure 14: Illustration of the three traffic management phases considered (from [168]).

Breaking the system down into traffic management phases represents a first and important step. However, it does little to address the problem associated with the multi-dimensionality of the system. The following section reviews techniques that may enable us to capture all its dimensions.

2.2.1 Relevance Tree Analysis

A relevance tree is a systematic and analytic method, as defined by the Futures Group [294], which consists in hierarchically breaking a large topic down into increasingly smaller subtopics and components. The structure obtained starts at a high level of abstraction to reach a finer level of detail as succeeding levels of the tree are reached. The end result consist in a visual tree-like hierarchical structure [77]. If performed properly, such decomposition may provide a better understanding of the problem considered, as well as a new and more perceptive way of looking at it [294]. This technique, however, requires some critical discernment in order for the analysis to be insightful.

2.2.2 Morphological Analysis

This complementary method, often used in conjunction with Relevance Tree Analysis [294], can be traced back to Ramón Lull (1235-1315) [135]. It was first applied in 1966 by Fritz Zwicky, a Swiss astronomer and astrophysicist, who used it to develop jet and rocket propulsion systems and propellants [344]. Morphological Analysis has since been extensively implemented in a variety of scientific disciplines and complex system engineering problems [30, 188]. MA is very attractive for multi-dimensional, usually non-quantifiable, complex problems [259] because it provides a structured, functional, and intelligent means to decompose the problem and generate alternatives [188]. Consequently, MA has been used as a basis for various concepts, such as the Interactive Reconfigurable Matrix of Alternatives (IRMA), developed by Engler et al. [90]. MA is implemented through a matrix of alternatives, or morphological matrix, which is generated by "identifying the major functions or characteristics of a system on the vertical scale, and all the possible alternatives (or system attributes) for satisfying the characteristics on the horizontal scale" [188]. Such method hence requires a good knowledge of the problem of interest. Because the high number of alternatives generated through MA may encumber its use [294], the IRMA extended the capability of the matrix of alternatives by incorporating new concepts such as filters, compatibility matrices, or Multi-Attribute Decision Making (MADM) techniques into the selection of product features [90].

2.2.3 Functional Induction

Functional induction is a method developed by de Tenorio et al. [76, 75], which aims at supporting and facilitating the development of architecture concepts. This method, which shows strong promises in the definition of aircraft architecture, draws on the relationships that exist between physical systems and their functionalities. It is composed of the three following steps:

- Functional description of subsystem alternatives: this step consists in identifying candidate subsystems and describing them in terms of the function(s) they fulfill and the one(s) they induce

- Functional qualification: this step consists in determining the flow of information implied by any given function

- Definition of architecture concept: this step consists in identifying "boundary" functions (i.e. the functions necessary for a given architecture) and, following the functional induction chain, to select a concept. An example of a functional induction chain is provided in Figure 15

The Adaptive and Reconfigurable Matrix of alternatives (ARM), along with the Functional Mapping Matrix (FMM) are tools that have been developed by de Tenorio et al. [76, 75] to facilitate and support the implementation of this method. More information about these tools can be found in [13].

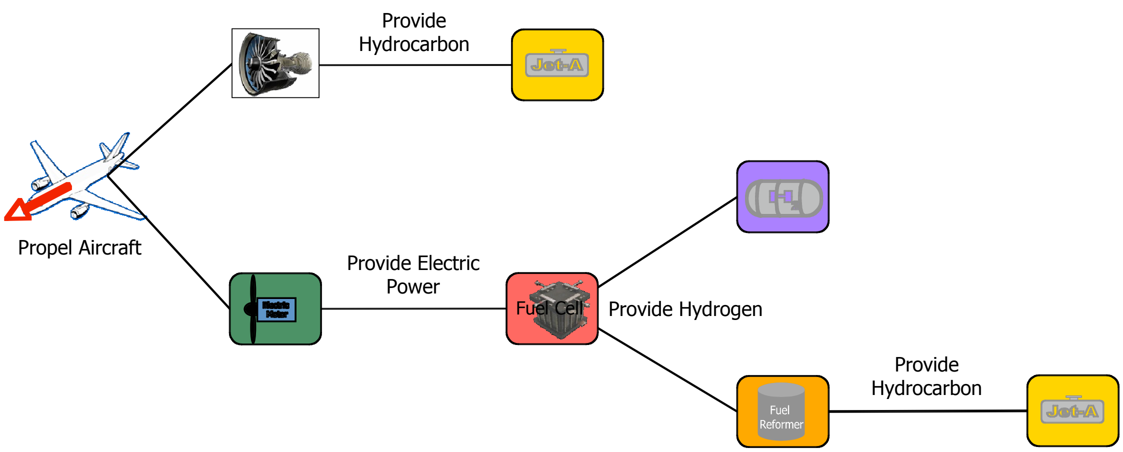


Figure 15: Example of a functional induction chain (from [76]).

2.2.4 Preliminary Observations

As previously mentioned, down-selecting technologies based on airport needs is an arduous task. In particular, the nature of the relationships between the different technologies, operational concepts, and operational improvements makes the identification and selection of necessary technologies particularly challenging. A method that provides a systematic, structured and traceable means to capture the multi-dimensionality of the problem is needed. Additionally, this method should enable or support:

- The generation of options or alternatives: the multitude of operational improvements, concepts and technologies need to be captured and represented
- The representation and integration of the interdependent nature of the relationships
- The filtering of information: all these options (operational concepts, technologies, etc.) will not be available at the same time. Given the year of acquisition or implementation considered, some technologies or operational concepts will only be partially available or not available at all. Filtering capabilities should thus be included into the selection process

Based upon these requirements and the review conducted above, the following hypothesis can be formulated:

Hypothesis 1.1: The combination of decomposition techniques such as relevance tree analysis and morphological analysis, along with filters and dependency tables provides the decision-maker with a rigorous, structured, and traceable process for technology selection

As previously mentioned, good investment decisions cannot be made without a prior understanding of the technologies in the context of their relationship with other technologies. However, while the decomposition proposed may support a rigorous approach to technology selection, it, alone, does not provide the full picture of the different causal relationships that may exist between technologies. Hence, while a mapping like the one provided in Figure 10 can help identify direct impacts, it is not suitable for the identification of indirect ones. However, indirect relationships, which are the result of cross-dependencies/effects, may be more important than direct relationships. A knowledge of how technologies impact each other is essential to the formulation of adaptable portfolios. Indeed, if an airport has, for example, already invested in Technology A, then it could make sense to invest in Technology B at a later date, if these two technologies have high cross impact scores. The causal relationships between technologies should thus be investigated and the full extent of the impacts of technologies on one another assessed. Numerous methods and tools exist that can be used to gain a better understanding of technology interrelationships and help identify impacts between them. The most relevant techniques are discussed in the following Section.

2.3 *Investigation of Causal Relationships between Technologies*

2.3.1 Relevance Tree Analysis

The organized and detailed structure of relevance trees, as described in Section 2.2.1, is particularly efficient in showing relationships of possible or probable outcomes [77]. As pointed out by Burgelman [47] and Bright [42], relevance tree analysis allows to quantitatively evaluate the relative importance of each element of the tree against explicit criteria, and a given scenario or future goal. The use of relevance tree analysis can thus provide quantitative information as to the importance of different relationships, but at the cost of heavy commitment of man-hours with often too value-laden estimation.

2.3.2 The Futures Wheel

The Futures Wheel, invented in 1971 by Jerome C. Glenn, is a method that visually supports the representation of complex issues and relationships [77, 137]. It is centered on a particular trend, event or theme, for which primary impacts and consequences are brainstormed. These primary impacts then get rise to secondary ones. Several rings of the wheel can thus be added through brainstorming strategies and questioning about the future, as illustrated in Figure 16 [77, 137]. Many versions of the Futures Wheel, such as the Implementation Wheel, Impact Wheel, Mind Mapping, and Webbing, have been developed since the first version in 1971 [137]. The Futures Wheel has been seen valuable to assess the broad impact of technology and identify positive and negative feedback loops. Also, because it is developed through systematic and analytical thinking, it provides a relatively explicit map of the potential complexity of interactions and may help identify patterns [137]. However, as mentioned by Glenn, its drawbacks are tightly tied to its strengths. Indeed, it is possible that the representation becomes too complex and overwhelming before any patterns can be revealed. Another inconvenient of this method, is that, like many others, it is highly dependent on the knowledge and expertise of the people who participated in its creation [137]. Therefore, the user should avoid drawing hasty conclusions but should use this tool as a basis for further thinking [137].

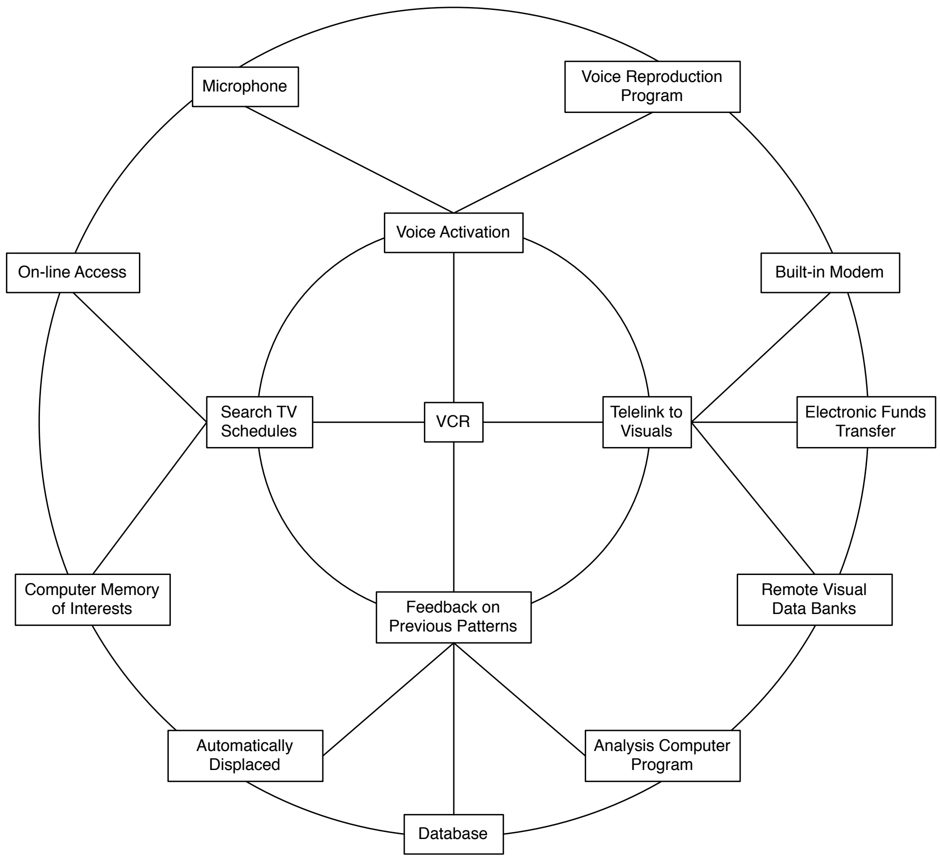


Figure 16: Example of a futures wheel (from [137]).

2.3.3 Causal Loop Diagrams

Causal Loops Diagrams (CLDs), also called Influence Diagrams, are visual representations of cause and effect relationships between individual system variables that, when linked, form closed loops. Causal loop diagramming is particularly present in the field of system dynamics modeling where it is used to describe positive (reinforcing) and negative (balancing) feedback processes [291]. A causal loop diagram consists of a set of nodes or variables, whose cause and effect relationships are represented by arrows carrying positive or negative signs. More specifically, the plus or minus sign at the head of each arrow indicates the direction of causality between the variables when all the other variables (conceptually) remain constant [291]. As a rule of thumb [214]:

- If variable A directly affects variable B, then an arrow from A to B links the two variables

- If a decrease in variable A causes a decrease in variable B, or if an increase in B results from an increase in A, then the change takes place in the same direction (reinforcing) and the arrow carries a “+” sign

- If a decrease in variable A causes an increase in variable B, or if an decrease in B results from an increase in A, then the change takes place in the opposite direction (balancing) and the arrow carries a “−” sign

Finally, the overall polarity of a feedback loop (whether the loop itself is positive or negative) is indicated by a “+” or “−” sign in the center of the diagram. A large “+” sign indicates a positive loop, while a large “−” sign indicates a negative loop. A generic causal loop diagram is represented in Figure 17.

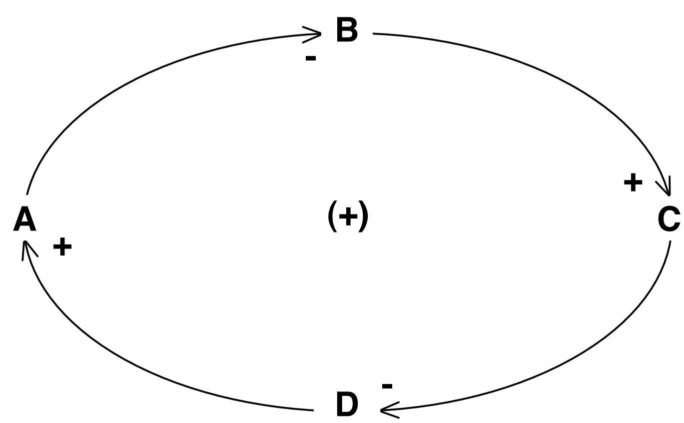


Figure 17: A generic causal loop diagram.

Causal loops diagrams are thus extensively used to analyze how interrelated variables affect one another. As such, they have been particularly efficient in fostering the understanding of internal and external driving forces in organizations and businesses [221]. The main drawback of this technique, however, is that it becomes quickly unmanageable as soon as the number of variables increases [172]. Setting up causal loops diagrams is also particularly time consuming and requires a good understanding of the system being modeled.

2.3.4 Cross-Impact Analysis

The concept of Cross-Impact Analysis (CIA) originates from a simulation game called "Futures", which was conceived and designed for the Kaiser Corporation by Helmer [150], and Gordon and Hayward [140] in the 1960s [257, 91]. As defined by Porter, the term "Cross-Impact" encompasses a group of various analytical techniques aimed at "addressing questions regarding points such as the probability, timing, severity, and diffusion of each impact; who will be affected and how; their probable response, and how significant the higher-order impacts will be" [257]. Enzer more specifically describes cross-impact analysis as "a family of techniques that tries to evaluate changes in likelihood of occurrence among an entire set of possible future events, and trends in light of limited changes in probability for some of the items of that set" [91]. Simply worded, CIA, through the cross-comparison of a given set of factors [257], helps study and assess the different interrelations between these factors [268]. As such, this set of techniques, as mentioned by Coates, provides a higher degree of analytical graininess than other techniques such as Delphi, for example [60].

CIA is implemented through the development of a cross-effect matrix. This matrix arrays two lists of factors, one vertically, and one horizontally [257]. It is then used to "evaluate outcomes considering the implementation or non-implementation of actions and the occurrence or non-occurrence of events" [91]. One of the purposes of such a matrix is thus to obtain a description of causal relationships between different factors or variables [91]. A cross-effect matrix for which the factors in both vertical and horizontal dimensions are identical is called a cross-impact matrix. There exist four main matrix formulations, as identified by Porter [257]:

- Technology $\times$ Technology: such a cross-impact matrix is often used to study how the development of one technology may affect the advancement of an other one

- Technology $\times$ Society: such a matrix may represent the societal impacts of technological activities

- Policy $\times$ Impacts: such a matrix may be used in policy analysis to portray the impacts that may result from the adoption of given policies

- Impacts $\times$ Impacts: such a matrix describes the way impacts from given activities or technologies interact to create other impacts

The information in the cells between each row and column can represent conditional probabilities, likelihoods of occurrence, or quantitative estimates of magnitude or importance [257, 91]. This information is mostly obtained from expert opinion or intuition [56]. A detailed description of the general process of CIA is provided by Porter et al. [257], and Gordon and Hayward [140]. Among the drawbacks and limitations of conventional CIA, Choi et al., and later Weimer-Jehle [326], mentioned the issue associated with requesting estimates from experts, where experts commonly represents "all those whose opinions may be useful to futures thinking" [260]. Indeed, information provided by experts is dependent on their background and level of knowledge, and is thus often subjective and intuitive. This in turn may lead to inconsistencies and discrepancies in the conditional probabilities [56]. Hence, it is possible that the estimated probabilities of a particular event may not represent a mathematically consistent set of probabilities [89]. As a result, probabilities often need to be adjusted during the process. This also makes the interpretation of forecasting or quantitative impact assessment results difficult [56]. Furthermore, a large number of experts is often needed to gain meaningful information [56]. Another limitation of this approach is that the impact intensity is dependent on the list of factors used in the matrix [140]. Finally, CIA only deals with pair-wise impact assessment. While determining the impact of more than two factors on a third one is theoretically possible, adequately estimating the conditional probabilities makes this task particularly challenging [140].

This technique has thus been revised several times since the 1960s in order to address these limitations. As such, a wide variety of qualitative, quantitative, or mixed versions, assessment tasks, and applications of CIA, have been developed [15, 140, 91, 257, 56, 172, 14, 301, 326, 327]. For example, CIA has been used to forecast scenarios, as well as the emergence of new technologies [91]. It has thus been widely adopted for long range planning and forecasting studies [268], and is now used in a number of forecasting areas [56]. Additional CIA studies have been conducted to help obtain a more accurate picture of the causal linkages coupling different factors or technologies [91]. Hence, some work has been focussing on estimating the nature and intensity of these relationships, as well as identifying key factors or technologies, in an attempt to focus policy actions or direct funding efforts [56, 172, 91]. Choi et al., for example, developed a methodology to study the relationships and impacts between technologies, using patent registration, classification, and information. In their work, a technology impact index, defined as a conditional probability between technologies, is computed to obtain the nature of the impact of a technology on another. Because in their study, conditional probabilities are measured using patent data, the authors thus claim to address the limitations associated with experts' qualitative judgement or intuition, and to provide a more quantitative CIA [56]. This impact index uses N(A), the number of patents including technology A, and $N(A \cap B)$, the number of patents including both technologies A and B, to evaluate the impact that technology A has on technology B (Equation 1). Then, by grouping these impact indices, the authors are able to identify impact patterns (Figure 18), and further describe the characteristics of the different relationships. As mentioned by Choi et al., in a bidirectional impact technology pair, "each technology affect the development of the other", while in an unidirectional impact technology pair, "a technology affects the other one but not vice versa." An additional interesting aspect of their work is the use of Network Analysis, a quantitative technique derived from Graph Theory, to identify the complex relations among three or more technologies. In a cross-impact network, edges and their direction represent the type and direction of impact between the different technologies (nodes). Technologies that have bidirectional or unidirectional impact with another technology are also identified (Figure 19). The methodology proposed by Choi et al. thus offers an interesting starting point to strategic decision-making. Indeed, the evaluation and further grouping of cross-impact indices may help identify causal relationships that may not have been apparent in the first place. Such information is essential to entities, such as airports, that wish to increase their technological capability.

$$Impact(A, B) = P(B \setminus A) = \frac{N(A \cap B)}{N(A)} \tag{1}$$

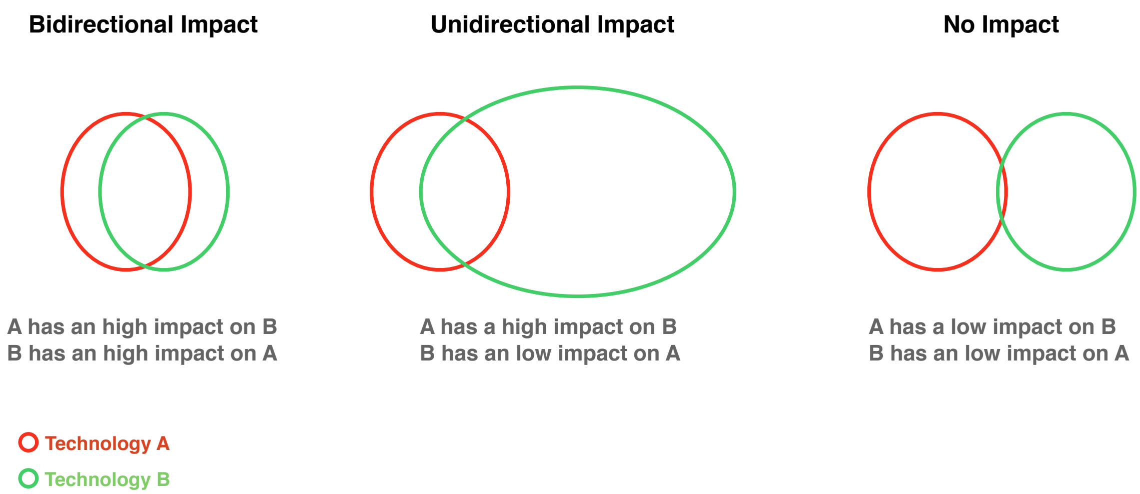


Figure 18: Types of cross impact patterns (adapted from [56]).

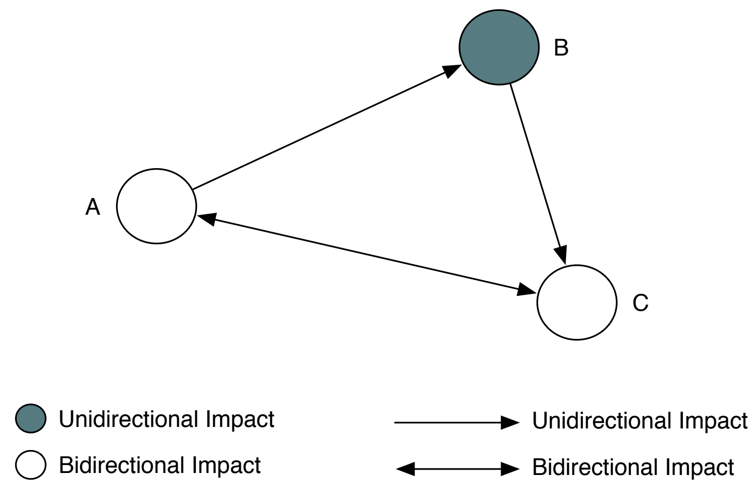


Figure 19: Example of a cross-impact network for technologies A, B, and C.

Thorleuchter et al. [301] developed an approach very similar to the one discussed by Choi et al. In their paper, the authors define a Compared Cross Impact (CCI) index to inform R&D decision makers of the "relative strength, relative weakness, and parity of the organization's R&D activities in technology pairs."

Jeong and Kim's work [172] focused on the identification of the key technology among future technologies. Their qualitative impact assessment method uses cross-impact matrices based on fuzzy relations and the development of inference algorithms to assess technology impacts. Because their work addresses the impact assessment of future technologies, linguistic terms such as Certain, Very Strong, Strong, Medium, etc. are used to represent the relative degree of impact for the cross-impact analysis. An interesting aspect of their study lies in the consideration of the time delay relationship between technologies, in other words, the amount of time that elapses between a seed technology and a goal technology. This time delay becomes the answer to the following question: "If we select technology A as the starting point, then how long does it take to get to advanced technology B when considering their technological dependence?" [172]. In their paper, this information is modeled by membership functions, described from expert inputs. The authors thus define the key technology as the one "with a high technological causality or the shortest possible time lag between a seed technology and a goal technology" [172]. The research conducted by Jeong and Kim presents a time component which was not present in the work by Choi et al. However, the relative degree of impact, while being described on a linguistic scale, remains provided by experts, as are the different membership functions that depict the time delay relation between technologies.

Other authors, such as Asan et al. [15] (2004) have based their work on the approach suggested by Jeong and Kim to "explore the future behavior of a system by studying a set of variables and their interactions" [15]. In their paper, they propose two fuzzy approaches to qualitative CIA: one focusing on linguistic variables and the other one focusing on TFNs (Triangular Fuzzy Numbers - a special type of fuzzy numbers), to reduce the complexity and determine variables that best describe their system of interest. Their research eventually proposes a classification of variables as key variables, influential variables, and dependent variables, which is then used to construct future scenarios.

Finally, Asan and Asan [14] (2007) improved the work by Asan et al. [15] by including time relationships to the general analysis of causal relationships. By introducing a time lag for each relationship, the authors thus proposed a complementary approach to the qualitative CIA that analyzes the impact of time on the interrelationships between variables. Their methodology consists in estimating time lags over causal impacts between pairs of variables. This information is then used to recompute cross-impacts and determinate indirect relationships according to the shortest possible time. Eventually, they propose to weight the revised impacts by time to classify variables with respect to their influence and dependence [14]. An interesting contribution of this work is that it provides a way to identify the emergence of indirect relationships with time. However, as most of the studies that have been conducted on impact analysis, the outcome of the proposed method is highly dependent on the experts opinion.

2.3.5 Preliminary Observations

Among the different methods and tools presented in this Section, Cross-Impact Analysis appears as the one having the most potential to help determine the causal impact between technologies and identify the nature of their relationships. The work by Choi et al. in particular holds promises regarding its use for the problem at hand. The following Hypothesis is thus formulated:

Hypothesis 1.2: The necessary information regarding causal impacts and complex relations among technologies for the problem of interest can be provided by the implementation of Cross-Impact methods.

As previously mentioned, making good investment decisions requires that the causal relationships between technologies be understood, and that their impact on the performance of airports be evaluated. Many challenges are associated with this last aspect. First, most of the technologies considered in this work are still currently underdevelopment, therefore their performance when they will enter the market is, at this time, unknown. As pointed out by Coates, “the newer the technology, the more intrinsic irreducible uncertainties there will be” [60]. Additionally, as discussed previously, most of these technologies are interdependent, making their impact assessment more challenging. Finally, the functionality and interest for ground technologies also depend on airborne technologies and aircraft level of equipage. Hence, it is likely that the impact of technologies at the airport level will depend on the number of aircraft adequately equipped or on the rate at which the corresponding airborne technologies will be infused or adopted onboard aircraft.

The following Sections offer a discussion about each of these challenges, at the exception of the last one. Although the aspect of technology infusion and diffusion is of great interest to the author, the time requirement for the realization of this research prevents its consideration. The following sections thus review the 2 first aforementioned challenges into more details. The aim of this discussion is to provide the reader with a better understanding of the issues to be overcome, as well as the different solutions that may be available.

2.4 Technology Futures Analysis Methods

Today's decisions are made based on today's available knowledge and information of what we expect the future to be. Predicting the future with certainty is impossible due to the complex interactions of technological, political, economical, environmental and social factors [306], and thus the presence of too many unknowns. However, some techniques exist, which, with some degree of confidence, can provide a possible range of alternative futures [255], and assist in reducing uncertainty and its associated risk [306]. As such, many methods exist that focus on analyzing future technologies and their impact. These methods (technology intelligence, forecasting, roadmapping, assessment, and foresight [292]) are briefly described in the following sub-Sections.

2.4.1 Technology Intelligence

Technology intelligence has been defined by Kerr et al. as "the capture and delivery of technological information as part of the process whereby an organisation develops an awareness of technological threats and opportunities" [186]. Technology intelligence originates from the need of companies to keep abreast of the latest technology developments and trends in order to ensure their future growth and the survival of their business. Through the involvement of internal and external experts, as well as external information services, technology intelligence helps identify technological development in time [198]. Thus it is an indispensable asset for strategic planning and decision making, particularly for technology-based companies [186].

2.4.2 Technology Forecasting

The Technology Futures Analysis Methods Working Group defines technology forecasting as "the systematic process of describing the emergence, performance, features, or impacts of a technology at some time in the future" [292]. Technology forecasting is thus concerned with the prediction of possible future states of technology [255]. The focus of a forecast is inherently linked to the type of decisions (strategic, innovative, operational, etc) it helps to make [306, 335]. Forecasting is thus above all an art, not a science [74]. Forecasts are based upon past events and/or behaviors. However, there is always a point in time where behavior changes. In other words, it is unlikely that an historical condition will persist forever [318]. As pointed out by de Neufville, "the past may well be prologue, but the past does not define the future" [69]. Despite its limitations in terms of reliability, forecasting has proven particularly valuable for industries experiencing relatively slow incremental changes, or in the short term where uncertainty is relatively small compared to the ability to predict [318]. Martino emphasizes that, to be of any value, a forecast should include the four following features: the technology being forecast, the time of the forecast (single point in time or time span), a description of the characteristics of the technology (given in terms of functional capability), and a statement of the probability associated with the forecast [213]. The goal of technology forecasting is thus to provide a quantitative indication of how a given technology performs with respect to time, after full-scale development has been achieved [306]. As such, as mentioned by Bright, it may be difficult, even infeasible, to forecast technologies that have not reached the latter stages of full-scale development [42].

There exists a wide variety of forecasting techniques and numerous schemes for categorizing or classifying them. Porter, for example, offers the following categorization (Table 4):

He also proposes to divide forecasting techniques into five categories: Monitoring, Expert Opinion, Trend Extrapolation, Modeling, and Scenarios [256]. Martino, on the other

Table 4: Categorizing technology forecasting methods [256]

Category	Definition	Applicable Forecasting Methods
Direct	Direct forecast of parameter(s) that measure an aspect of the technology	Expert opinion (Delphi, Surveys, Nominal group, etc.) Naive time series analysis Trend extrapolation (Growth curves, Substitution, Life cycle, etc.)
Correlative	Correlative parameters(s) that measure the technology with parameters of other technologies or background forecast parameters	Scenarios Lead-lag indicators Cross impact Technology progress functions Analogy
Structural	Explicit consideration of cause-and-effect relationships that affect growth	Causal models Regression analysis Simulation models (Deterministic, Stochastic, Gaming) Relevance trees Mission flow diagram Morphology

hand, identifies four basic methods often used in combination, namely: extrapolation, leading indicators, causal models, and probabilistic methods [213]. Finally, another classification, suggested by the Institute for Water Resources, divides methods into extrapolative and normative types, as illustrated in Table 5. Extensive description of these methods can be found in [256, 306, 213].

2.4.3 Technology Roadmapping

Garcia and Bray define technology roadmapping as "a needs-driven technology planning process to help identify, select, and develop technology alternatives to satisfy a set of product needs" [134]. Technology roadmapping is thus a tool for collaborative technology planning which, through the solicitation of expert opinions, create a best guess of a development timeline for a particular technology [332, 134]. As described by Garcia and Bray, the technology roadmapping process, which is illustrated in Figure 20, consists of

Table 5: Types of forecasting (from [161])

Extrapolative	Normative
Intuitive Forecasting	**Morphological Analysis**
- Conjecture	
- Brainstorming	
- Heuristic programming	
- Delphi	
Trend Extrapolation and Correlation	**Technology Scanning/Contextual Mapping**
- Trends	- Functional array
- Breakthroughs	- Graphic models
- Precursor events	
- Correlation and regression	
Metaphors and Analogies	**Decision Theory**
- Growth	- Decision trees
- Historical	- Relevance trees
- Simulation	
Scenarios	**Scenarios**
- Surprise-free	
- Canonical variations	
Dynamic Modeling	
- Gaming	

three phases: (1) Preliminary activity, (2) Development of the technology roadmap, and (3) Follow-up activity [134]. This process enables the identification of critical technologies and technology gaps to eventually provide a development timeline, path, and alternatives, that will lead to better technology investment decisions [332, 134]. Technology roadmapping has been applied in a wide range of industries such as pharmaceuticals, aerospace, manufacturing, nanotechnology, power generation, electronics, etc. [332].

Phase I.	**Preliminary activity**
	1. Satisfy essential conditions.
	2. Provide leadership/sponsorship.
	3. Define the scope and boundaries for the technology roadmap
Phase II.	**Development of the Technology Roadmap**
	1. Identify the "product" that will be the focus of the roadmap.
	2. identify the critical system requirements and their targets.
	3. Specify the major technology areas.
	4. Specify the technology drivers and their targets.
	5. Identify technology alternatives and their time lines.
	6. Recommend the technology alternatives that should be pursued.
	7. Create the technology roadmap report.
Phase III.	**Follow-up activity**
	1. Critique and validate the roadmap.
	2. Develop an implementation plan.
	3. Review and update

Figure 20: The three phases in the technology roadmapping process (from [134]) .

2.4.4 Technology Assessment

Technology assessment is defined by Coates as "the systematic identification, analysis, and evaluation of the real and potential impacts of technology on social, economic, environmental, and political systems and processes" [59]. It is a policy analysis process, which especially focuses on the unintended or delayed impact that the introduction, extension, or modification of a technology may have [60, 61]. The end goal of technology assessment is to present the decision-maker with a detailed group of options, alternatives, and implications [61]. Coates identified the following steps for a comprehensive technology assessment [60]: (1) Examine problem statement, (2) Specify systems alternatives, (3) Identify possible impacts, (4) Evaluate impacts, (5) Identify the decision apparatus, (6) Identify action options for decision apparatus (7) Identify parties of interest, (8) Identify macro system alternatives (other routes to goal), (9) Identify exogenous variables or events possibly having an effect on steps 1 through 8, and (10) Conclusions (and recommendations). A more detailed description of this process can be found in [60, 61]. Many techniques have been used for technology assessment in the past, and include: Delphi, Cross-impact analysis, Trend extrapolation, Morphological analysis, Decision and relevance trees, Economic techniques (virtually any technique of economics), System analysis, Simulation, Modeling, Scenarios and games, Moot courts, Surveys, Decision theory, Scaling, Brainstorming, Graphics, or Judgment theory. A more comprehensive discussion about some 89 technology assessment studies, along with their associated techniques and methods, can be found in [59].

2.4.5 Technology Foresight

Technology foresight, which is probably the most upstream element of the technology development process [308], was first used in Japan in the 70's and introduced in European countries in the early 90's. As defined by the United Nations Industrial Development Organization (UNIDO), technology foresight "provides input for the formulation of technology policies and strategies that guide the development of the technological infrastructure" [308]. This approach promoted by UNIDO is thus now commonly used to help formulate technology policies and strategies in the mid-future, and measure the impact of science and innovation policies on the society and the environment [201, 292]. Technology foresight is conducted through Delphi surveys, and workshops and seminars, bringing together members from both the industry and academia. This approach has been particularly successful in rising the society's awareness about the future, and promoting sustainable and innovative development for a more desirable future [308, 292].

All of these techniques (technology intelligence, forecasting, roadmapping, assessment, and foresight) offer different, though often overlapping, ways to analyze future technologies and their impacts [292]. Recently, these techniques have been brought under an umbrella defined by the Technology Futures Analysis Methods Working Group as Technology Futures Analysis (TFA) [292]. Tables 6 to 9 present a compilation of the different TFA methods, as suggested by the Technology Futures Analysis Methods Working Group [292]. Other classifications, such as the one proposed by Porter [257] or Tran and Daim [302], exist.

The attributes used by the Technology Futures Analysis Methods Working Group in their taxonomy are the following [292]:

- Methods are classified into nine "families": Creativity, Descriptive and Matrices, Statistical, Expert Opinion, Monitoring and Intelligence, Modeling and Simulation, Scenarios, Trend Analyses, and Valuing/Decision/Economics

- Methods can be "hard" and/or "soft". "Hard" methods make use of quantitative (empirical, numerical) information, while "soft" ones are mostly qualitative (judgmentally based, reflecting tacit knowledge)

- Methods can be normative and/or exploratory. Normative methods will initiate the process with a need in mind, while exploratory ones will begin the process using extrapolation of current technological capabilities

Table 6: TFA methods (from [292])

Methods (and variations)	Family	Hard or Soft	Exploratory or Normative
Action (options) analysis	Valuing/Decision/Economic	Soft	Normative/Exploratory
Agent Modeling	Modeling and Simulation	Hard	Exploratory
Analogies	Descriptive and Matrices	Hard/Soft	Exploratory
Analytical Hierarchy Process (AHP)	Valuing/Decision/Economic	Hard	Normative
Backcasting	Descriptive and Matrices	Soft	Normative
Bibliometrics (research profiling patent analysis, text mining)	Monitoring and Intelligence /Statistical	Hard/Soft	Exploratory
Brainstorming (brainwriting, nominal group process (GNP))	Creativity	Soft	Normative/Exploratory
Causal Models	Modeling and Simulation	Hard	Exploratory
Checklists for impact identification	Descriptive and Matrices	Soft	Exploratory
Complex Adaptive System Modeling (CAS) (Chaos)	Modeling and Simulation	Hard	Exploratory
Correlation Analysis	Statistical	Hard	Exploratory
Cost-Benefit Analysis (monetized and other)	Valuing/Decision/Economic	Hard	Exploratory
Creativity Workshops (future workshops)	Creativity	Soft	Normative/Exploratory
Cross-Impact Analysis	Modeling and Simulation /Statistical	Hard/Soft	Exploratory
Decision Analysis (utility analysis)	Valuing/Decision/Economic	Soft	Normative/Exploratory
Delphi (iterative survey)	Expert Opinion	Soft	Normative/Exploratory
Demographics	Statistical	Hard	Exploratory
Diffusion Modeling	Modeling and Simulation	Hard	Exploratory

Table 7: TFA methods (continued) (from [292])

Methods (and variations)	Family	Hard or Soft	Exploratory or Normative
Economic Base Modeling (input-output analysis)	Modeling and Simulation /Valuing/Decision/Economic	Hard	Exploratory
Field Anomaly Relaxation Method (FAR)	Scenarios	Soft	Normative/Exploratory
Focus Groups (panels, workshops)	Expert Opinion	Soft	Normative/Exploratory
Innovation System Modeling	Descriptive and Matrices	Soft	Exploratory
Interviews	Expert Opinion	Soft	Normative/Exploratory
Institutional Analysis	Descriptive and Matrices	Soft	Exploratory
Long Wave Analysis	Trend Analysis	Hard	Exploratory
Mitigation Analyses	Descriptive and Matrices	Soft	Normative
Monitoring (environmental scanning, technology watch)	Monitoring and Intelligence	Soft	Exploratory
Morphological Analysis	Descriptive and Matrices	Soft	Normative/Exploratory
Multicriteria Decision Analysis (Data envelopment analysis (DEA))		Hard	Normative
Multiple Perspectives Assessment	Descriptive and Matrices	Soft	Normative/Exploratory
Organizational Analysis	Expert Opinion	Soft	Exploratory
Participatory Techniques	Expert Opinion	Soft	Normative
Institutional Analysis	Descriptive and Matrices	Soft	Exploratory

Table 8: TFA methods (continued) (from [292])

Methods (and variations)	Family	Hard or Soft	Exploratory or Normative
Precursor Analysis	Trend Analysis	Hard	Exploratory
Relevance Trees (futures wheel)	Descriptive and Matrices /Valuing/Decision/Economic	Soft	Normative/Exploratory
Requirements Analysis (need analysis, (attribute X technology matrix)	Descriptive and Matrices Valuing/Decision/Economic	Hard/Soft	Normative
Risk Analysis	Descriptive and Matrices /Statistical	Hard/Soft	Normative/Exploratory
Roadmapping (product-tecnology roadmapping)	Descriptive and Matrices	Hard/Soft	Normative/Exploratory
Scenarios (scenarios with consistency check, scenario management)	Scenarios	Hard/Soft	Normative/Exploratory
Scenario Simulation (gaming, interactive scenarios)	Scenarios /Modeling and Simulation	Soft	Normative/Exploratory
Science Fiction Analysis	Creativity	Soft	Normative
Social Impact Assessment (socioeconomic impact assessment)	Descriptive and Matrices	Soft	Normative/Exploratory
Stakeholder Analysis (policy capture, assumption analysis)	Descriptive and Matrices Valuing/Decision/Economic	Soft	Normative

Table 9: TFA methods (continued) (from [292])

Methods (and variations)	Family	Hard or Soft	Exploratory or Normative
State of the Future Index (SOFI)	Descriptive and Matrices	Hard/Soft	Normative/Exploratory
Sustainability Analysis (life cycle analysis)	Descriptive and Matrices Modeling and Simulation	Hard	Exploratory
Systems Simulation (system dynamics, KSIM)	Modeling and Simulation	Hard	Exploratory
Technological Substitution	Modeling and Simulation	Hard	Exploratory
Technology Assessment	Descriptive and Matrices /Modeling and Simulation	Hard/Soft	Exploratory
Trend Extrapolation (growth curve fitting and projection)	Trend Analyses	Hard	Exploratory
Trend Impact Analysis	Trend Analyses/Statistical	Hard	Normative/Exploratory
TRIZ	Creative	Hard	Normative/Exploratory
Vision Generation	Creative	Soft	Normative/Exploratory

However, which techniques to use is essentially context dependent [257], and "inevitably affected by data, time, and resources availability" [292]. In particular, as pointed out by the Technology Futures Analysis Methods Working Group, the time horizon strongly affects methodological appropriateness. The technologies of interest in the context of this work call for a long time-frame to be considered. Hence, techniques belonging to Trend extrapolation, Statistics, or Modeling should be excluded [257, 292], while methods involving Expert opinion and Scenarios should be preferred [257]. Additionally, because we are not interested in what the performance of a given technology needs to be in the future, normative methods can be discarded. **Consequently, for the purpose of this work, techniques involving expert opinion, and knowledge gained from the literature will be used to identify the impacts that each technology considered will have on the performance of the system**. This work also considers new and unfamiliar technologies for which very little is known about their capabilities [290]. Indeed, some of these technologies have not been field-tested or implemented yet. Consequently, given the uncertainty and the present lack of knowledge regarding their performance, impact ranges obtained from studies and expert opinion will be preferred to single values.

As mentioned by Asan et al. [15], and Asan and Asan [14], one of the major limitations of many future research methods is that they only produce information in isolation [15, 14], meaning that a given impact is often determined without accounting for other factors of influence, such as other technologies. Thus, while assessing the impact of each technology independently is necessary, it is not sufficient to properly assess the impact that combined technologies may have on the system.

The interdependency of technologies has already been touched on in Section 2.1 and illustrated in Figures 10(a) and 10(b). The following section presents an example of operational concept to illustrate in more details the different levels (functional, technological, etc.) of dependencies that may exist, and the challenges associated with them. It also discusses methods that can potentially capture the impact of combined and dependent technologies.

2.5 Assessing the Impact of Combined and Dependent Technologies

The operational concepts being developed by SESAR and JPDO are not tailored to any particular type of airport, though most of them will exhibit their full applicability and benefits at large, complex and highly congested airports [103]. European programs only focus their effort on the implementation of technologies on large international airports. U.S. programs, on the other hand, consider both large and smaller airports (with significant numbers of operations) and try to accommodate smaller airports with more affordable and simple systems to allow them to reach levels of safety equivalent to larger airports [52]. Among the various operational concepts under development or deployment, the concept of Advanced Surface Movements Guidance and Control System (A-SMGCS) is one that is flexible enough to meet the needs of different types of airports, including regional airports [322]. Some background and principles regarding A-SMGCS are provided in the subsection below. The aim of that section is 1) to demonstrate the complexity of the relationships between each constituent of an A-SMGCS and 2) to illustrate the interdependencies between its enabling technologies.

2.5.1 An Example

The concept of a Surface Movement Guidance and Control System (SMGCS), which was first proposed by the International Civil Aviation Organization (ICAO) in 1974 [103], mainly consists of “a manual system relying almost exclusively on human skills to maintain a safe ground movement environment" [103]. Today, most airports already have some sort of SMGCS, which usually includes surface movement radars (SMR) and/or signs, stop bars, switchable center line lights, etc. Between the 80’s and early 90’s,SMGCS capabilities in terms of surveillance and guidance started showing some limitations. As the traffic kept increasing, the number of incidents on the ground started rising as well [103]. SMGCS limitations were even more perceptible under low visibility conditions [322]. The concept of Advanced Surface Movement Guidance and Control System (A-SMGCS), first described in 1990 [103], has thus been developed to overcome the shortcomings of SMGCS and address the increase in number of incursions as well as the difficulty to maintain airport throughput in low visibility conditions [317, 322, 103]. When on the ground, and particularly during taxi operations, the cockpit crew controls the aircraft manually and navigates with paper charts or maps, while air traffic controllers (ATCOs) look out the window to estimate aircraft positions or ensure that separation standards are respected [52]. In bad weather conditions, the ATCOs are limited by the primary airport radar capabilities (existence of “blind spots" due to airport structures [53] and no possibility to know objects' identity) and must follow special visibility procedures to ensure safety. These, added to complex airport layouts and cockpit crews that might be unfamiliar with the airport layout and taxi routes, result in increasing delays that pass on to the approach areas and the overall air transportation system [168, 218]. The primary goal of A-SMGCS is thus to better manage the traffic on the aerodrome surface [168, 218], and to provide solutions to airport capacity issues [240] by enabling traffic throughput to keep up with demand, particularly under adverse weather conditions.

2.5.1.1 Principles

A-SMGCS, as defined by the ICAO (International Civil Aviation Organization), provides routing, guidance and surveillance for the control of aircraft and vehicles in order to safely maintain the declared surface movement rate under all weather conditions with the Aerodrome Visibility Operational Level (AVOL) (the minimum visibility at or above which the declared movement rate can be sustained) [163]. This modular system, represented in Figure 21, consists of the following operational functions:

- Surveillance: Surveillance services consist in accurately detecting, positioning, identifying, and classifying all aircraft, vehicles and obstacles in the maneuvering and movement areas by providing data about the actual traffic situation at the airport and around it (i.e. final approach and initial departure) [321, 168, 163, 52]. It is essential that the Surveillance function be accurate to avoid limitations on the performance and use of the other functions [240]. Surveillance can either be cooperative or non-cooperative. Cooperative surveillance includes Mode-S Multilateration and ADS-B, while non-cooperative surveillance is generally enabled by Surface Movement Radars and Terminal Approach Radars [322]. The surveillance function is the enabler for the remaining functions and should thus be implemented first [322]

- Control/Monitoring: Control services are responsible for preventing collisions and incursions into runways and restricted areas by detecting and alerting on conflicts, incursions and planning deviations on the taxiway, apron and gate areas [321, 168, 52, 163]. Their implementation ensures safe, prompt and efficient movements [163]. This function requires the technology related to Surveillance to be implemented first [100]

- Routing/Planning: Routing services generate taxi routes and plans for ground movements [321, 168, 52] such that aircraft and vehicles move from their current position to their intended position in a safe, prompt and efficient manner [163]. These functions relate mostly to taxi routing and departure/arrival sequencing [52]

- Guidance: Guidance services help pilots and vehicle drivers implement clearances and instructions given by the controller, and prevent them from missing their assigned routes and from intruding into restricted areas [321, 168]. Guidance can be achieved through various means: ground-based guidance means (signs, lights, stop-bars, etc.), follow-me cars, instructions by voice, or data link transmission [168, 52]. However, the performance of the guidance systems is highly dependent on the efficiency and accuracy of the surveillance function [52, 240, 163]

This system also requires data communications as well as a Human/Machine Interface (HMI). Services to aircraft (pilots) and ground-vehicle (drivers) are provided as follow [321]:

- Airborne services: Airborne services to the flight crew include surveillance (position of aircraft with respect to airport layout, as well as position and identification of surrounding traffic), conflict detection (to prevent collisions with other traffic and incursions in restricted areas), control (non-time-critical clearances and routing information), guidance (to support the flight crew for maneuvers on the ground), as well as other functions

- Vehicle services: Drivers are provided with positioning, route information, route guidance, incursion prevention, and position information on the site of an emergency

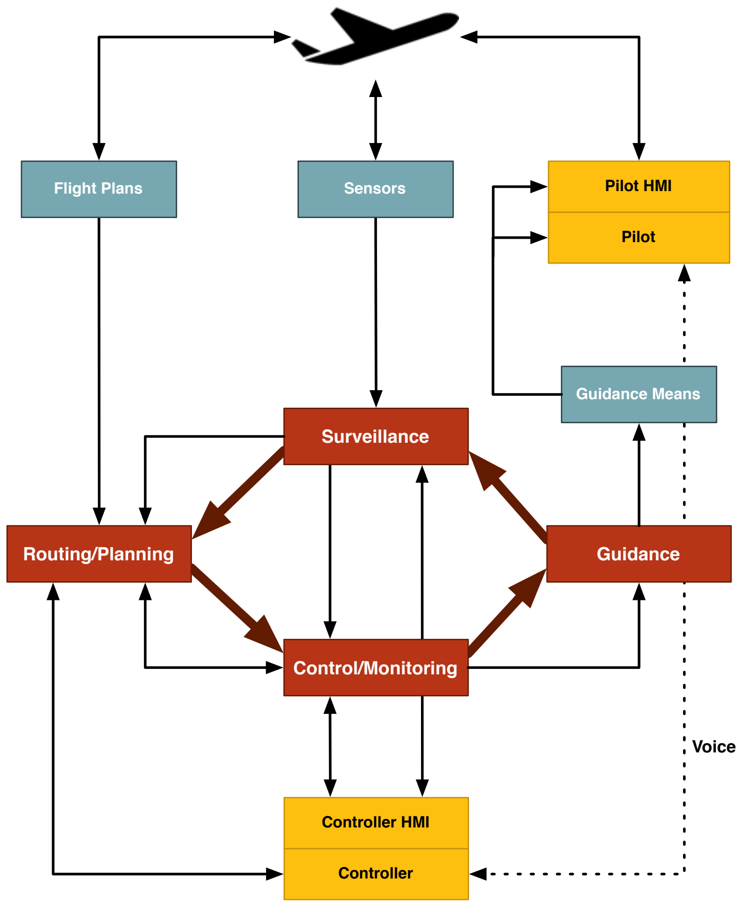


Figure 21: A-SMGCS operational concept (from [240]).

Enabling technologies for each of the aforementioned functions are provided in Figures 22 and 23.

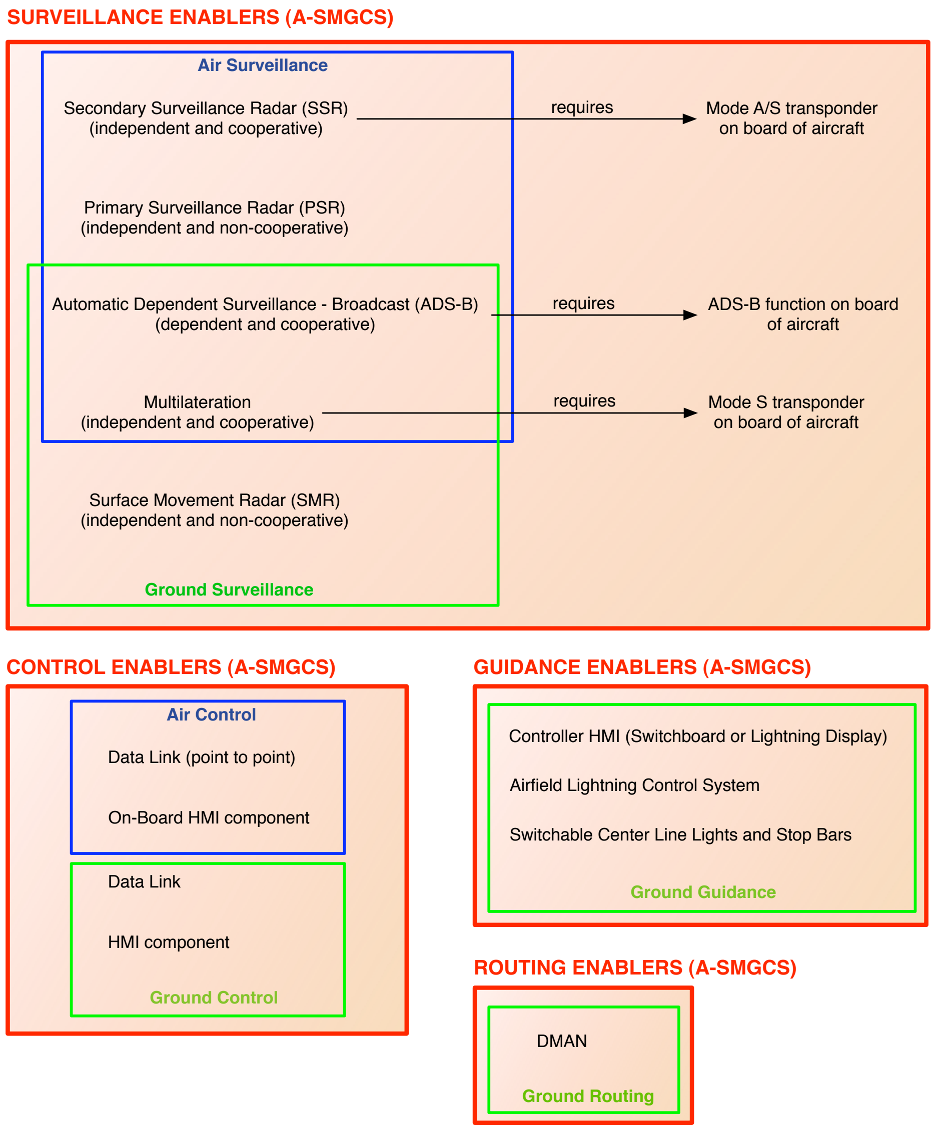


Figure 22: A-SMGCS technology enablers (adapted from [88, 169]).

Figure 23: A-SMGCS technology enablers for pilots and vehicles (Adapted from [169]).

A few observations can be made from this quick review of the A-SMGCS principles and enabling technologies.

2.5.2 Primary Observations

The example provided in this section illustrates dependencies at the functional level. As illustrated in Figure 24, the functions mentioned above depend on one another, with the Surveillance function being a pre-requisite to the implementation of the other functions. Consequently, it is expected that limitations in the performance of one function (lack of accuracy of the Surveillance function for example) may reduce the performance of other dependent functions and components [218].

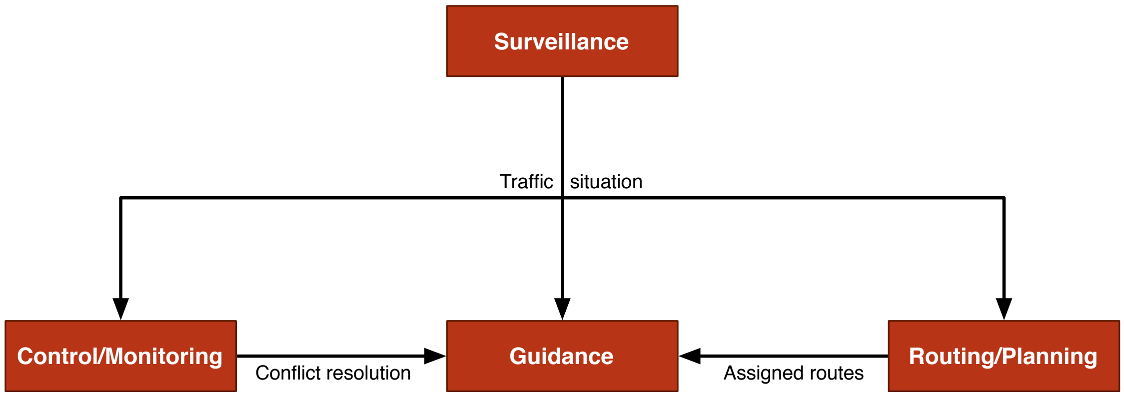


Figure 24: Example of dependencies between A-SMGCS functions (from [100]).

Additionally, the full implementation and effectiveness of certain functions is highly dependent on the equipment status of aircraft and other vehicles, as illustrated in Figures 22 and 23. For instance, the functions enabled by an Automatic Dependent Surveillance-Broadcast (ADS-B), which is a surveillance technology that broadcast GPS-based position from aircraft to ground-based receivers and other aircraft, depend on aircraft operational capability (i.e. the type of avionics and transponder onboard the aircraft) (Figure 25) [230]. Therefore, as mentioned by Carotenuto [52], it is possible that certain functions or capabilities may not be achievable until all aircraft and vehicles are suitably equipped and cooperating. It is thus likely that the performance of ground technologies depends on the number of aircraft adequately equipped or on the rate at which the corresponding airborne technologies are installed onboard aircraft. However, as mentioned in Section 2.3.5, the aspects related to technology infusion, diffusion, adoption, or substitution are not considered in this research. Hence, from this point forward, the performance of ground technologies is solely a function of their causal relationships with other ground technologies. In other words, the necessary airborne technologies are assumed to be in place and fully operational.

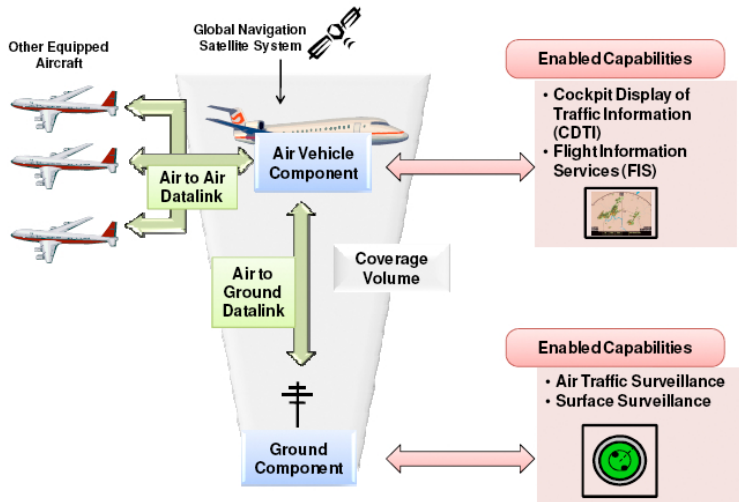


Figure 25: High-level ADS-B architecture (from [230]).

As discussed in Section 2.3, the evaluation of correlation factors between technologies allows to identify the nature of the impact that one technology has on another. To be of any practical interest, these impacts, which can be of three types - bidirectional, unidirectional or null (Figure 18), need to be translated into performance indicators and quantitatively evaluated at the airport level. This requires that:

- An evaluation environment be provided. The evaluation of the combined impact of technologies on the overall performance of an airport is too expensive to be conducted at a real airport. To alleviate this issue, the National Science Foundation (NSF) advocates the use of Modeling and Simulation (M&S). Hence, the NSF notes that M&S "provides a powerful alternative to the techniques of experimental science and observation when phenomena are not observable or when measurements are impractical or too expensive" [239]. Aspects related to Modeling and Simulation are discussed in Section 2.5.3

- A method be implemented that helps define the impacts of technologies on the metrics of the system. In other words, the impact that technologies may have on technical metrics needs to be captured and further translated into system metrics. Lets assume, for example, that Technology A provides a reduction in longitudinal separation (technical metric). The deployment of such a technology would allow aircraft to fly closer from each other, therefore possibly increasing airport capacity (system metric). The evaluation of technology impacts, to be of any value to the decision-maker, must thus be conducted at both the system and the technical levels. This aspect is further discussed in Section 2.5.4

- "Performance rules" be defined for each impact type. While it is reasonable to assume, for example, that the combined performance of two independent technologies be the sum of the performance of each individual technology, the combined performance of two dependent technologies (having either a uni- or bi-directional impact on each other), on the other hand, becomes much more difficult to define

As discussed, evaluating the impact of technologies on airport performance measures cannot, for obvious reasons, be done at a real airport. A popular yet very efficient way to alleviate this issue is through the use of Modeling and Simulation (M&S) for which a brief description is provided in the following Section.

2.5.3 The Need for Modeling and Simulation

A model, as defined by Coates, is "any systematic interrelationship of elements and components into a system which is intended to parallel in structure, form or function some real world system" [61]. Simulation implements models over time to help understand the behavior of the system being modeled [79]. Modeling and simulation (M&S) has become a popular yet very powerful discipline, and is now one of the most commonly used methods in Operation Research (OR) and management science for the study and understanding of complex systems [199, 236]. Modeling and simulation has also proven to be a crucial enabler of decision support systems and has been used extensively for tactical and strategic decision making across various fields of study, disciplines and industries. Its applicability ranges all the way from Aerospace Engineering to Agriculture (farm management, etc) [18], Forestry (resource management, operational strategies, etc.) [251, 190], Pharmaceutics (drug development, etc.) [227], etc. More particularly, the use of modeling and simulation has provided, over the years, a certain number of advantages [199, 325, 273, 299, 236, 54, 79, 165]:

- It is often the only technique to study complex, real-world systems exhibiting stochastic or deterministic, static or dynamic, and continuous or discrete characteristics
- It allows the performance of an existing system to be evaluated under different scenarios, conditions, design alternatives, or operating strategies, as often as necessary, and this without disrupting the existing system
- It provides a better understanding of the behavior of the system being modeled and has been proven very valuable for the exploration of inter-relationships, interdependencies and sensitivity analysis
- It assists in identifying and solving bottlenecks
- It enables quantitative technology evaluation
- It permits months or even years of activity to be simulated in just a few minutes of computer time
- It can take into account uncertainty
- It helps reduce the cost and risk of life cycle activities

A Modeling and Simulation environment is thus a pre-requisite for the proper assessment of the combined impact of technologies on the performance of an airport. Methods have been proposed that leverage modeling capabilities to simulate technology impacts. The technique that is the most relevant to this work is described and discussed in the following section.

2.5.4 Simulating Technology Impacts

Simulating technology impact is essential to quantitatively capture the benefits or degradations on the metrics of the system. A particularly relevant approach, developed by Kirby and Mavris, consists in modeling technologies through incremental changes in technical metrics [188, 187, 215]. In particular, they introduce the concept of technology impact factors, or "k" factors. These k factors are, in essence, scale factors added within a M&S environment to model changes introduced by new technologies on those metrics. Vectors of k-factors, or technology vectors, are then defined for each technology whose elements consist of the benefits and degradations associated with the technology. Technology vectors are further compiled into a Technology Impact Matrix (TIM). A TIM, such as the one shown in Figure 26, thus provides the contribution of each technology on various technical metrics.

		Technologies		
		T1	T2	....
Technical Metrics	Longitudinal Separation	+4%	~	
	Lateral Separation	+5%	-10%	
	....			

Technology vector

Figure 26: Notional example of a technology impact matrix.

The impact of technical metrics on the system metrics can then be further "assessed quantitatively through a linear or higher order sensitivity analysis and formulated in a metamodel" [187]. A metamodel, or surrogate model, is an approximation of an existing model. A surrogate model has often been described as some kind of transfer function that would map or approximate the relationships between responses (output) and input variables [29]. Surrogate models can be created through various processes, one of which, response surface methodology [233], has been gaining a lot of popularity in the aerospace community.

The quantitative method of technology assessment proposed by Kirby and Mavris has been widely demonstrated and used in previous studies. In particular, as noted by Biltgen [30], “the k-factor technique has been proven to work well with surrogate models.”

In conclusion, the focus on surrogate modeling as a means to evaluate system metrics and the use of “k-factors” to represent technical impacts, seem to provide an appropriate framework for enabling quantitative technology evaluation at the airport. One last aspect to address, as mentioned in Section 2.5.2 is the need to define “performance rules” for each type of impact.

2.5.5 Defining Performance Rules

Past evaluations of combinations of technologies using the approach proposed by Mavris and Kirby assumed that the technical impacts of individual technologies are additive [188]. While such an assumption appears valid when studying disciplinary subsystems, it does not hold anymore when looking at airport technologies (refer to Sections 2.1 and 2.5.1). Hence, new performance rules, based on the assumption that the combined impact of two technologies depends on how correlated those technologies are, need to be investigated and defined (Figure 67).

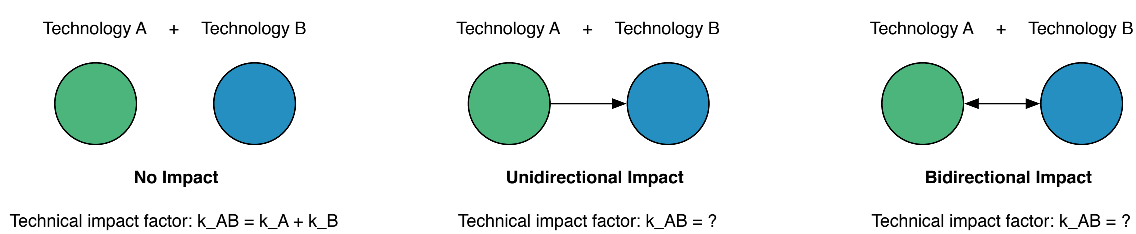


Figure 27: Need for performance rules for technologies having a uni- or bi-directional impact on each other.

Based on the discussion provided in the sections above, the following assertion can be made regarding the impact assessment of combined and interdependent technologies:

Assertion 1.1: The impact of interdependent technologies can be captured through the use of "k-factors" to represent technical impacts, the definition of performance rules based on technology causal relationships, and the development of a surrogate model to evaluate system metrics.

As mentioned in Section 2.5.3, the use of Modeling and Simulation, and particularly the creation of surrogate models is paramount to the proper assessment of the technology impacts represented by k-factors. The following section provides a synopsis of state-of-the-art modeling tools, software and platforms of interest for this research. The review of existing tools allowed the author to identify whether or not existing capabilities could be leveraged to help meet the objectives of this research.

2.6 Review and Summary of Existing Modeling Tools, Software and Platforms:

Significant work and extensive research have been geared towards the development of decision-making support tools to assist the airport community and its various stakeholders in their planning and design decisions. Different simulation tools, platforms and analytical models have thus been developed over the years to assist in identifying bottlenecks, conducting trade-offs and impact analysis, and assessing airport performance and technological capabilities.

Analytical models are usually built from a set of relatively straight-forward equations, while simulation models are more complex and generate performance outputs that are probabilistic [328]. As stated by Ignaccolo [159], analytical models are more difficult to apply or do not imitate complex systems well enough, mainly because the theoretical probability distributions embedded in them are sometimes very different from operational reality.

A brief description of the tools, platforms, and models pertaining to strategic airport planning and airport airside performance assessment is provided below. A more exhaustive review of available models and tools can be found in [243, 339, 338, 341].

Simulation tools:

Airport and Airspace Simulation Model (SIMMOD):

SIMMOD is a tool originally sponsored by the FAA which is widely used for strategic decision making, operational decision making and cost/benefit analysis in the aviation community [296]. This is a microscopic, stochastic, event-driven tool that considers aprons and taxiways, runways and final approach, and terminal area airspace [74] and provides airfield capacity as well as delay analysis [339]. As mentioned by Zografos [339], "SIMMOD can be used to simulate in detail: a full individual airfield (including runways, taxiways and apron areas); an airfield and its associated terminal airspace; a regional system of aiports and the associated airspace; or, a regional volume of airspace." Examples of outputs include: aircraft travel times, traffic flows, throughput capacity per unit of time, delays by time of day and location on the airfield or in the airspace, and fuel consumption [74]. It allows users to gain a very good understanding of ATM and airport operations, but at the expense of a steep learning curve, significant amount of training and time spent preparing the input files and processing the output files [296].

Total Airspace and Airport Modeler (TAAM):

TAAM is a widely used high fidelity tool [85] developed by the Preston Group (TPG) in cooperation with the Australian Civil Aviation Authority (CAA) that considers aprons and taxiways, runways and final approach, and terminal area airspace [74] to provide airfield capacity and delays [339]. As mentioned by Zografos [339], "TAAM can be used as a planning tool or to conduct analysis and feasibility studies of ATM concepts." However, TAAM is also known for being computationally intensive and requiring extensive data preparation and long training times [74].

Airport Machine:

The Airport Machine is a commercial simulation package developed by Airport Simulation International (ASI) that considers aprons and taxiways as well as runways and final approach [74] to provide airport capacity and delay analysis [296]. This tool "covers all aircraft activities from a few minutes before landing until a few minutes after take-off" [296], but is known to have a steep learning curve [74].

Flexible Airport Simulation (FLAPS):

FLAPS has been developed by Flight Transportation Associates, Inc and allows for the study of runway capacity, delays and the complete landing process [296]. According to the FLAPS' webpage (www.ftausa.com), this model includes "detailed representation of runway layout and availability, aircraft characteristics and mix, and air traffic control operating procedures."

Boeing Airport Capacity Constraints Model:

This tool, developed by Boeing is intended to "evaluate the reduction in theoretical hourly airport capacity due to constraints caused by airfield configuration or operational procedures", but also to "quickly evaluate a range of enhancement alternatives" for the 35 OEP airports [8]. The model is composed of a single runway capacity constraint model and a runway interaction and airfield constraint model. It considers inputs such as airport fleet mix, runway length, runway exit location, and airplane performance, and required longitudinal and lateral separation minima [8]. This tool is part of the Evaluation and Analysis Division (EAD) Modeling and Analysis Framework, the EAD being the division in charge of "providing the knowledge necessary to help prioritize JPDO investments" [148].

Airport Capacity Analysis Through Simulation (ACATS):

ACATS is an airport capacity analysis tool developed by Mitre/CAASD that considers only the airside of the airport. It "simulates the runway capacity of any airport operating under any user-specified ATC rules, operational constraints, and traffic patterns" [342] but does not allow for trade-offs analysis between capacity and other airport performance metrics [342]. The final testing and validation of this tool is still ongoing [342].

Analytical models:

Master Airfield CApacity and Delay (MACAD) Model:

MACAD has been developed within the framework of the MANTEA (Management of Surface Traffic in European Airports DG XIII) project funded by the European Commission [247]. It integrates different macroscopic models for the analysis of runway systems and apron areas [279]. It has been shown to be fast, flexible and easy to use, which makes it a good tool for strategic decision-making purposes [279]. MACAD is described by Zografos et al. [339] as “an integrated macroscopic airside model that provides an overall assessment on the capacity and delays of the airside. [...] It is hybrid (includes a macroscopic simulation model), dynamic (captures the dynamic nature and characteristics of airport operations), and stochastic (takes into account the randomness of the arrival and service operations).” In general, it provides an overall assessment of the airside operations [339]. As detailed by [279, 342], MACAD is sensitive to most of the major parameters that affect airfield capacity and level of service (delays), including airport geometry and operational characteristics, characteristics to the local air traffic control system, operational characteristics of the airside, and the characteristics of the demand for airfield access and services. It was evaluated and validated at Rome’s Fiumicino Airport and further applied at six major European airports.

Enhanced Airfield Capacity Model (E-ACM):

The E-ACM, developed by MITRE, is an update to the FAA Airfield Capacity Model [288]. This model has been used to assess the impact of separation rules, ATC procedures, aircraft performance, and runway configuration on airport capacity [342, 295]. More particularly, it provides the average number of arrivals and departures that can be expected during busy periods at an airport based on the factors aforementioned [295]. It has recently been used to produce capacity estimates for the FACT 2 analysis [295]. While fast and easy to use, this tool is however not suitable for the study of complex airport systems [342].

Simulation platforms:

Reorganized ATC Mathematical Simulator (RAMS):

RAMS is a tool developed and supported by the Model Development Group (MDG) at EUROCONTROL that provides for 4-dimensional flight profile calculations, 4-dimensional aircraft conflict detection, 4-dimensional aircraft maneuvering for conflict resolution and 3-dimensional airspace [117]. It considers the terminal area airspace and some of its outputs include simulated aircraft statistics, sector statistics, delays and characteristics of conflicts and resolutions. Its main drawbacks are poor post-processing capabilities and outputs that consist of large, unprocessed output files [243].

The Aviation System Analysis Capability (ASAC):

ASAC (NASA) is an integration of tools and expert knowledge aimed at better understanding and assessing the impact of advanced aviation technologies on the U.S. economy [200]. Two particular models, the Airport Capacity Model and the Airport Delay Model, have been developed to evaluate the impact of technologies on airport capacity (constrained by arrival runway occupancy time and separation between aircraft in the terminal environment [296]) and delay. The Airport Capacity Model uses inputs such as weather, FAA procedures, traffic characteristics, aircraft type, and technology levels to characterize airport capacity. The Airport Delay Model then uses the results provided by the Airport Capacity Model along with weather data and demand patterns to determine delays. As mentioned by Lee [200], some of the model limitations include ignoring runway closure situations and the lack of a surface-movement component. Also, this model does not consider delays attributable to airline scheduling practices, neither does it consider schedule disruptions or flight cancellations in case of severe weather [200]. Then, because this tool is a queuing model that assumes random arrivals of aircraft in the queue, it does not consider any presequencing. Finally, the accumulation of delays as the day progresses are not account for.

The Commonly Agreed Methodology for Airport airside Capacity Assessment (CAMACA):

The Commonly Agreed Methodology for Airport airside Capacity Assessment or CAMACA has been developed by Eurocontrol (www.eurocontrol.int/camaca) to help airports in making more efficient and knowledgeable decisions with regard to their operations. It is composed of three modules, the Runway system capacity assessment, the Taxiway system capacity assessment and the Apron system capacity assessment. CAMACA allows the user to study the impact and benefits of changes in airport layout and configuration. The overall goal of CAMACA is to allow airports to identify scenarios that will help them unlock their latent capacity [100, 93]. Examples of CAMACA outputs include: hourly runway capacity as a function of the proportion of flight arrivals, hourly arrivals vs departures capacity, nodes that are particular conflict points, and amounts of time expected to be lost per node, average length of queues that form on each link, apron capacity as a function of stand capacities, as well as flights accommodated on each stand and average apron occupancy and utilization per hour [93]. This tool was first used in the late 1990s by Brussels airport. Finally, because no thorough assessments of the tool limitations have been conducted, no drawbacks or limitations have been identified.

Optimization Platform for Airports, including Landside (OPAL):

The OPAL project has been funded by the European Commission, Directorate General for Energy and Transport, under the Fifth Programme on Competitive and Sustainable Growth [336]. It enables the assessment of overall airport performance by considering both landside and airside. In particular it is capable of performing capacity and delay optimization of total airport operations: "this optimization part enables the user to optimize an airport configuration, given a scenario, the selected airport modeling tools and an optimization criterion (e.g., level of service, safety, noise, and cost)" [261].

One of the particularities of the OPAL platform is that it integrates different legacy tools used for safety, environment and cost-benefit analysis. These tools are [261, 337, 319]:

- Capacity and delay
  - Macro Cargo Simulator(MACS)
  - MANTEA Airfield Capacity and Delay (MACAD)
  - Passenger/Baggage Flow Model (PAX/BAX)
  - System Dynamics Passenger Flow Model (PowerSim)
  - Simple Landside Aggregate Model (SLAM)
  - Airport and Airspace Simulation Model (SIMMOD)
  - Total Airspace and Airport Modeler (TAAM)
  - Passenger Flow Model (Witness-MODA)
- Safety
  - Traffic Organization and Perturbation AnalyZer (TOPAZ-TAXIR)
  - Third Part Risk Analysis Package for Accident Accident around Airports (TRI-PAC)
- Environment
  - Integrated Noise Modeler (INM)
- Cost-Benefit
  - Cost-Benefit Model (CBM)

OPAL has been used successfully for practical cases at Amsterdam, Athens, Frankfurt, Madrid, Palma de Mallorca and Toulouse airports [261].

Supporting Platform for Airport Decision-making and Efficiency Analysis (SPADE):

The SPADE platform is a project that has been co-funded by the European Commission within the Sixth Framework Programme (2002-2006) and coordinated by the same team who worked on the OPAL platform. It started in May 2004 with an expected duration of 18 months and was built on previous models and tools such as OPAL. SPADE is a decision support tool intended for airport stakeholders and policy makers that aims at supporting decisions "related to the strategic-policy, tactical-policy, and operational-policy decision-making for both airside and landside, separately or in combination" [340]. SPADE addresses changes both in demand (traffic patterns, airlines' fleet, etc.) and in resources (in airport layout, airport configuration, runway configuration, new technologies, etc.). Based on a particular scenario the platform can perform capacity, delay, safety, security, noise, level of service, and cost-benefit analyses [237].

The Performance Indicators Analysis Tool for Airports (PIATA):

The Performance Indicators Analysis Tool for Airports (PIATA), developed by Eurocontrol, is based on Microsoft Excel and Palisade Corporation "RISK". It has been developed to help improve surface movement efficiency and capacity at airports by conducting probabilistic analyses of a variety of performance indicators such as runway occupancy times (ROT), arrival/departure demand, push back delay, departure/arrival sequence efficiency and departure/arrival separation efficiency [100, 99].

2.6.1 Simulation/Modeling needs

Given the nature of the system to be modeled, it is important that the modeling tools, software or platform being chosen have the following characteristics:

- Dynamic: considers inputs that are time-dependent to capture fluctuations in performance over time
- Stochastic: considers the randomness associated with traffic for example. This is essential to capture the impact of uncertainty on the different performance metrics
- Parametric: provides answers that are more than point solutions
- Affordable: does not require excessive manpower commitment or computer time
- Quantitative: assesses the performance of the system through metrics
- User-friendly: is intuitive and includes visualization techniques
- Flexible: allows the user to test a wide variety of scenarios and conduct trade-offs between various airport performance metrics with minimal modifications
- Integratable: facilitates future development and/or the combination with other tools
- Accepted: recognized by the community as being a valid tool or environment

The existing simulation tools and platforms described above are qualitatively assessed with regard to the aforementioned characteristics. Figure 28 summarizes the current evaluation of the different tools based on information found in the literature.

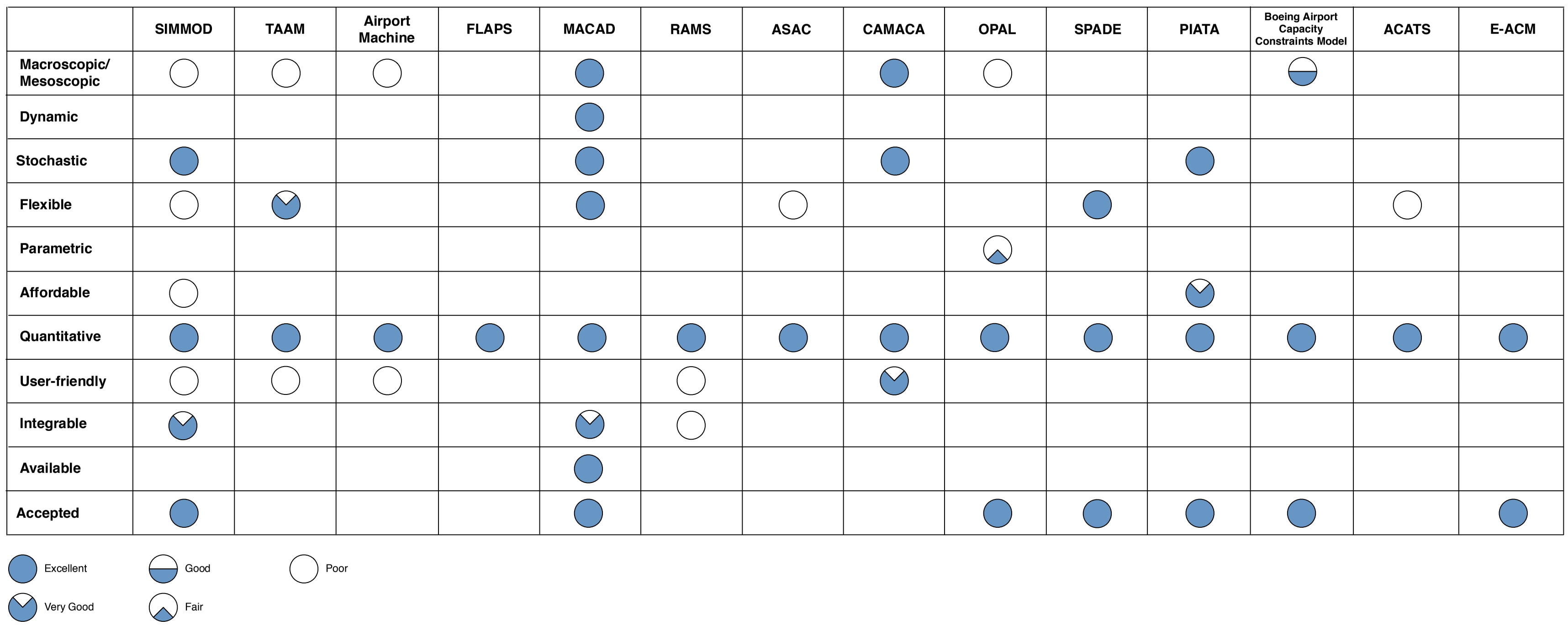


Figure 28: Qualitative assessment of existing tools.

While these tools have proven valuable, some exhibit limitations or particular issues. First, most of these tools have been developed with large airports in mind, meaning airports for which large and detailed amounts of data are available. Also, most of them are not user-friendly as they require the user to have particular computational expertise as well as a significant amount of time to prepare input files, build baseline and what-if scenarios, or process output files [342]. Then, another drawback of some of these simulation tools, as mentioned by Zografos [339], is their “lack of documented integration capabilities." Additionally, a typical limitation of microscopic models in general is that the expertise required to run them is too important and the learning curve too steep, to make them appropriate tool for strategic decision support [342]. Furthermore, they sometimes lack flexibility, appearing as “black boxes." Their original underlying assumptions, when mentioned, can rarely be easily modified, which makes defining new operational procedures for each of the constraints embedded in the code too time consuming or impossible [279, 243, 8]. As such, these tools are not always suitable for the modeling and evaluation of new ATM concepts and/or technologies, and high-level airport decision making in general [342]. Finally, the lack of standardized measures of airport effectiveness or real harmonization of input requirements [342], make the comparison of these tools with each other a very difficult if not impossible task.

Eventually, the choice of the model used for this research is dictated by the research needs, the tool's capabilities, its acceptance by the community but also mainly by its availability. Based on these characteristics and the review conducted, MACAD is chosen to model and evaluate the impact of technologies on the airport performance.

Assessing the performance of a set of technologies is important. However, investing in technology portfolios cannot solely be based upon performance evaluation. Any evaluation of an investment is biased if its value to the investor is not properly assessed and communicated as well. The concept of value is thus omnipresent, and central to decision-making [41]. But what is value? There exist as many definitions of the word value as there are fields or disciplines. Value commonly describes the difference between what is paid (the exchange value) and the perception of the usefulness of a particular good, and the amount of money one is ready to pay for it (perceived use value) [38]. The perception of how useful a good is, hence its value, tend to differ if the purchaser is a company or a regular person. For example, a company may perceive an opportunity to make some profit as a need. Such perception, as mentioned by Bowman and Ambrosini [38], "requires the purchaser to have great insight into the cause-effect linkages between the use value of the resource and the ultimate delivery of profit". Hence, value is directly linked to the environment and economic circumstances affecting the consumer [38, 274], and is therefore particularly impacted by the factors endogenous and exogenous to that environment [41].

Uncertainty and change are intrinsic to any discipline, field of study or environment, and the air transportation industry is not immune to these attributes. Changes in aircraft types, technologies, airspace users, and the liberalization and privatization of airlines, as discussed in Section 1.6, have strongly impacted airports. Increase in air traffic has also prompted new safety regulations and audits that encourage airports to invest in new safety-related sensors, runway incursion protection and/or situational awareness systems [152]. To adapt or comply with new regulations, airports are forced to invest in infrastructure, navigation aids, lighting systems, personnel, etc., which carry significant increases in annual operating costs [152]. These investment decisions are often difficult and risky, particularly for regional airports, as the information on which they are predicated on is often only partially available or subject to change with limited predictability. This brings us back to the second assertion made in Chapter 1:

ASSERTION 2: The development of secondary and underutilized airports will be successful if the impact of changes on the system can be captured.

Our world is continuously changing and our ignorance about how (direction) and to what extent (scale) it may change results in uncertainty [87]. Uncertainty, as explained by Twiss [306] and D'Avino [68], is thus caused by a lack of information or factual knowledge about how the future may unfold. Uncertainty is usually reduced through the gathering and/or generation of necessary data, or managed through the formulation and adoption of strategies. Hence a plethora of techniques aimed at managing uncertainty fall under the concept of strategic planning. The following paragraphs briefly describe strategic planning and its limitations, and further discuss its application and alternatives with respect to airport planning and development.

2.7 Strategic Planning

Introduced in 1955, strategic planning was originally an organization's process [45] and management activity defined as a "disciplined effort to produce fundamental decisions and actions shaping the nature and direction of an organization's (or other entity's) activities within legal bonds" [245]. More particularly, it is aimed at helping organizations "conceive a desired future, as well as the practical means of achieving it" [4]. This disciplined process includes [258, 74, 49]:

- Assessing the current situation of an organization's activity, its mission, and guiding principles, as well as the organization's environment, and contextual factors
- Analyzing the organization's internal resources and assets
- Defining the organization's objectives and vision of how that organization should position itself with respect to its customers and competitors

- Formulating strategies that have a potential to attain these objectives, along with the barriers to their implementation and their potential outcomes. Evaluating them with respect to one another, and describing and detailing a strategic plan

- Making the resources, assets, and personnel allocation decisions necessary to support the strategic choices that will best accomplish the vision and objectives

- Measuring, monitoring and tracking how the organization is performing

Strategic planning can be implemented through various means [195]. Hence, many generic techniques of strategic planning exist, each of them having different flavors with respect to their properties, outcomes, and processes [258, 74]. These techniques include, for example, SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats), PEST analysis (Political, Economic, Social, and Technological), STEER analysis (Socio−cultural, Technological, Economic, Ecological, and Regulatory factors), or EPISTEL (Environment, Political, Informatic, Social, Technological, Economic and Legal).

Some of the value attributed to strategic planning lies in the fact that it allows organizations to analyze and reflect on their resources, their environment, and their visions, to help them formulate the path forward. Through the formulations of strategies, managers are encouraged to identify potential risks and opportunities and define contingency plans. These aspects of strategic planning are important, and explain to some extent its success. However, as discussed in the following section, limitations to strategic planning exist.

2.7.1 Limitations and Challenges of Strategic Planning

Most managers and planners have been enthusiastic about strategic planning since its inception. However, its implementation has not always been covered with success and much has been published regarding its pitfalls. Among the fallacies of strategic planning described in the literature, the one regarding prediction is the most emphasized. According to many, assuming that the world holds still while plans and decisions are being formulated and later implemented is at the origin of the many failures of strategic planning. Courtney et al., for example, stated [65]:

> "At the heart of the traditional approach to strategy lies the assumption that by applying a set of powerful analytic tools, executives can predict the future of any business accurately enough to allow them to choose a clear strategic direction. In relatively stable businesses, that approach continues to work well. But it tends to break down when the environment is so uncertain that no amount of good analysis will allow them to predict the future."

Another recurrent reason to explain some of the failures of strategic planning is formalization. Hence Mintzberg [229] advises managers to "leave their strategies flexible" and encourages planners to provide managers with "alternative conceptual interpretations of their world", in place of arbitrary formalized plans. Mintzberg also attributes what he calls "the fall of strategic planning" to the confusion that exists in managers' mind between strategic planning, referred to as strategic programming, and strategic thinking, described as a company's vision and global perspective: "(...) many practitioners and theorists have wrongly assumed that strategic planning, strategic thinking, and strategic making are all synonymous, at least in best practices" [229]. In other words, Mintzberg argues that strategic planning should be the means by which a strategic vision materializes, but should not, in any way, be mistaken for the vision itself. In his view, strategic planning without a vision and the support of the management is doomed to failure.

Some have opposed Mintzberg's idea of a fall of strategic planning. Godet, for example, states that "in fact, there is no risk of a fall because of the independent nature of each of its constituents. An organisation can plan (take the future into consideration) without actually committing to planning (a formal procedure) even if it does draw up some plans (explicit intentions)" [138]. He further explains the disagreement concerning the future of strategic planning by the confusion or lack of rigor that exist in the way people define strategic planning or strategic management.

As previously mentioned, strategic planning has been praised very early on by organizations in general, and managers in particular. It has thus been implemented in a variety of activity sectors and domains. The following section discusses strategic planning in the context of airports.

2.7.2 Airport Strategic Planning and its Alternatives

Airport strategic planning (ASP) was first developed in the 1960s. It differs from the managerial view of strategic planning in the sense that the emphasis and focus are not so much on the procedures and methods as they are on the role and behavior of each airport with respect to the system [74]. More particularly, ASP focuses on developing plans that describe the short- (five year), medium- (six to ten year) and long-term (twenty year) plans for airport development [195, 196]. Airport master plans represent the traditional approach to ASP. Numerous airports have been developed or modernized according to these plans, which are defined by ICAO as "the planner's conception of the ultimate development of a specific airport" [162]. An airport plan is required from any airports seeking federal funding [74, 277] under the provisions of the Airport and Airway Improvement Act of 1982 (in the United States) [119]. It is a comprehensive study that addresses the architectural and engineering developments at a single airport, but does not, however, specify any operational concepts or management issues [195]. Airport strategic planning exists at different levels (federal, state, regional/metropolitan, local), each of them exhibiting different funding mechanisms and sources, eligibility status and approvement process, planning documents and timeframes, directives and advisory circulars (AC), etc. Examples of planning documents, directives, and timeframes for each level are illustrated in Table 10 [115]. ASP also provides many benefits, as discussed in the Airport Cooperative Research Program (ACRP) Report on *Strategic Planning in the Airport Industry* [6].

Table 10: Airport planning at different levels

Level	Planning Directive	Planning Document	Time-frame
Federal	Order 5090.3C	National Plan of Integrated Airport System (NPIAS)	5 year plan, updated every two years
Metropolitan Statewide Regional	AC 150/5070-7	Airport System Plan	updated periodically
Local	AC 150/5070-6B	Airport Master Plan	20 year plan or ultimate buildout, updated periodically
Project specific	Order 5100.39C	Airport Capital Improvement Plan	2-5 year program updated annually

The main steps in the ASP process, and thus the definition of an AMP, however, remain identical and consist of [196]:

- Analyzing current conditions
- Creating an aviation demand forecast
- Assessing the facility needs and requirements to handle the forecasted demand
- Developing and evaluating several alternatives to achieve these requirements
- Developing the best alternatives into a detailed Master Plan

Airport master plans (AMPs) represent the traditional way to address uncertainty in airport planning in the case of individual airports [195]. They are solely based on the Terminal Aerodrome Forecast (TAF), which is an unconstrained demand forecast [277, 195] provided and updated by the FAA Office of Aviation Policy and Plans (APO) [141]. Hence, these plans are inherently static and reactive in nature [74]. Indeed, while they recognize the uncertainty of this single type of forecast to a certain extent, AMPs only propose one prospective response to one specific future [74, 207]. The rigidity of these plans, more than the erroneous and inadequate forecast used to develop them, is at the origin of many of the airport development failures discussed in Section 1.6. As stated by Karlsson

[183], “it is this reliance on specific forecast values that makes most airport plans incapable of dealing with high levels of uncertainty.” As stated in the Airport Cooperative Research Program (ACRP) Synthesis 2 addressing airport aviation activity forecasting [277]:

> “Airport forecasting studies often neglect the issue of uncertainty. Most often, forecasts are presented only as point estimates, although it is common to also present alternative “high” or “low” estimates that are based on differing assumptions about external factors thought to affect the forecast. Although this can provide a reasonable range of estimates, there are additional sources of uncertainty related to the statistical properties of the model.”

Additionally, because airport master plans do not consider alternative futures, but instead focus on describing a future long-range vision [74], they quickly become obsolete. Airport managers are often forced to drop the ultimate 20-year vision of the master plan after only 3 to 5 years [74], making the plans impossible to implement [195]. Hence, master plans actually account for less than half the projects built by the end of the planning horizon [207], in turn resulting in unnecessary investments in airside and landside facilities, inability to satisfy demand, etc. [195]. Accounting for uncertainty is thus crucial in an environment that is becoming more and more dynamic. As previously discussed by Karlsson [183], high uncertainty means that airports are faced with multiple futures. Hence, overlooking a large part of this uncertainty and relying on a single comprehensive solution have a strong potential to lead to wrong decisions and costly failures [195, 183]. This is particularly important as investment decisions made today, strongly impact the realm of future possible developments. In other words, solely considering aviation forecasts as the premise for new Master Plans greatly jeopardizes the airports’ viability [195]. However, despite the fact that the need to account for uncertainty has now largely been recognized, the airport planning community still relies heavily on the use of forecasts for airport strategic planning [183].

Many have voiced their concerns and criticisms over such planning practices, and have called for a more proactive and flexible master planning process that would include alternative sequences or types of developments [71, 74, 207, 195, 194, 183, 48]. Hence, approaches to airport master planning are evolving, as discussed in the two following sections.

2.7.2.1 The Scenario-Based Alternative

In 2000, Godet [138] noted that "the last two decades have seen the popularity of strategic planning through scenarios soar, especially among large corporations". However, it is only recently that the FAA has considered, at a very small scale, the use of a scenario-based approach to airport strategic planning [173] to address, to some extent, the multitude of futures that airports may face. A more consistent use of a scenario-based approach has however been adopted by the National Aeronautics and Space Administration (NASA) and the Joint Planning and Development Office (JPDO) Futures Working Group (FWG) to develop long-term strategies regarding the development of the air transportation system [173]. While the scenario-based approach to strategic planning provides a valuable alternative, Jimenez emphasizes that "the evaluation and selection of scenarios is notably lacking in transparency, traceability, and methodological formalism" [173].

Additionally to this scenario-based approach, four alternatives to airport strategic planning have recently emerged. These more proactive and flexible approaches - Dynamic Strategic Planning (DSP), Adaptive Policy-Making (APM), Flexible Planning (FP), and Adaptive Airport Strategic Planning (AASP) - are described in the following section.

2.7.2.2 The Flexibility-Based Alternative

- Dynamic Strategic Planning (DSP): Dynamic Strategic Planning (DSP) is an approach proposed by De Neufville and Odoni [74] that enables the definition and development of flexible plans and policies to allow airports to react proactively to opportunities or threats they may perceive as the future unfolds [194, 71]. These plans are thus by nature dynamic - they adjust over time to new conditions - and present a multi-stage flexible development. Dynamic strategic plans focus on identifying the most appropriate initial developments that “permit effective responses to future opportunities and developments” [74]. As such, they only commit to a first stage, but offer different developments in the subsequent stages, hence providing the flexibility to adapt as conditions change [194]. In summary, DSP [183]:

  – Acknowledges that long-term forecast are never accurate at best, and wrong at worst
  – Proposes flexible plans that can address high levels of uncertainty and satisfy multiple futures: plans consider a range of forecasts instead of one single forecast, as it was the case in the master planning process [74]
  – Helps decide which decisions to implement and when

As discussed in Section 2.9.1, the overall approach followed by DSP is not new and has been recommended before [71]. According to De Neufville [71], one of the originalities of DSP lies in the specific methods (Modeling, Optimization, Estimation of Probabilities, Decision Analysis, Sensitivity Analysis, Evaluation of Real Options, Analysis of Implicit Negotiation) used to identify the most effective types of flexibility and opportunities for long-term agreements between stakeholders. DSP thus focuses on the implications of implementing the above technique, and provides a set of general guidelines to planners and managers. It is suitable for all airports [183], though it fails to provide a clear and defined process as to how it should be conducted, hence making it difficult for airport decision makers to know how to use it in practice [194, 183]. General discussions and case studies describing the implementation, or potential implementation of DSP, at Pease, Kuala Lumpur/International and Schiphol Airports can be found in [194, 183, 74] respectively.

- Adaptive Policy-Making (APM): Adaptive Policy-Making (APM) is based on the observation that fixed and static policies are likely to fail when implemented in a dynamic environment [194]. Kwakkel [194] has compared APM to the route of a ship that adapts to changing events, but always takes the ship to its final destination. The process for APM is composed of two phases: a thinking phase, during which the adaptive policy is developed, and an implementation phase, during which it is implemented and adapted when necessary [194]. More information about the APM process and its constituents can be found in Walker et al. [323].

- Flexible Planning (FP): Burghouwt [48] is among the ones who advocate for a more flexible and pro-active approach to airport strategic planning and traditional airport master plans. The approach he defines as Flexible Planning draws strongly from the DSP alternative proposed by DeNeuville. His approach, however, calls for airports to shape their future and environment through their own actions. Hence Flexible Planning builds on the use of scenarios and the definition and implementation of incremental and phased developments projects. It also emphasizes the need to consider contingency planning in case of unforeseen or less desirable conditions, as well as the need to account for every stakeholder's preferences when making decisions.

Tables 11 through 12, provided by Kwakkel [194, 193], summarize the main differences between airport master planning, dynamic strategic planning, adaptive policy-making, and flexible planning. An additional comparison between a traditional master plan and a dynamic strategic plan can be found on page 42 of Maldano's dissertation [207].

Table 11: Comparison of master planning, dynamic strategic planning, and adaptive policy making (from [194])

Characteristics	Master Planning	Dynamic Strategic Planning	Adaptive Policy−Making
Focus	Blue print design of future airport	Flexibility in the plan so changes are possible if necessary	Vision of a future airport, realization of which is prepared by identifying different routes to realize this vision
Treatment of Uncertainty	Only demand uncertainties are considered and reduced through demand forecasting, other uncertainties are ignored	Key uncertainties that can influence the performance of the plan are identified and treated quantitatively through subjective probabilities	Key uncertainties that can influence the performance of the plan are identified and treated qualitatively
Response to unexpected developments	Unexpected events are treated in an ad hoc manner	A dynamic strategic plan contains pre-specified actions in the form of real options, which can be exercised if this will contribute to the performance of the plan	An adaptive plan contains pre-specified actions (e.g defensive and corrective actions) that are triggered when unexpected events lead to unwanted outcomes
Involvement of stakeholders	Limited stakeholder involvement, which can lead to serious opposition	Stakeholders are involved after the dynamic plan has been designed (i.e. a design- and defend- approach)	No clear specification of how stakeholders should be involved
Monitoring of outcomes on an ex-post basis	Limited monitoring, mainly as part of the decision making process about when to cash the Real Option. The outcomes to be monitored are those that influence the value of the Real Options	Outcomes would be monitored	Outcomes would be monitored as part of the implementation process. The outcomes to be monitored are based upon the objectives of the policy

Table 12: Comparison of dynamic strategic planning, adaptive policy making, and flexible planning (from [193])

Aspect	Dynamic Strategic Planning	Adaptive Policy–Making	Flexible Planning
Focus	Flexibility in a plan created through real options	Starts from a vision of the decision-maker and creates a plan for realizing this vision and protecting it from failure	Extends the focus of DSP by adding pro-active planning and contingency planning
Types of uncertainties considered	Emphasis on demand uncertainty, but other types of uncertainties could be considered as well via real options	Any uncertainty can be considered	Emphasis on demand uncertainties as driven by airline network developments, but in principle open to all types of uncertainties
Consideration of different futures	Via a staged development	Via hedging and mitigating actions	Via scenario robustness
Flexibility of resulting plan	Flexibility of plan is guaranteed via real options	Flexibility of the plan is addressed via the establishment of a monitoring system and pre-specification of responses	Flexibility of the plan is guaranteed via real options and contingency planning
Planning process	Seven categories of activities specified, but their relationships to each other and how they constitute a planning process remain unclear	Has a clear planning process, with a distinction between a thinking phase and an implementation phase	No clear process is specified

- Adaptive Airport Strategic Planning (AASP): Adaptive Airport Strategic Planning originates from the intent of Kwakkel et al. [193] to combine the three previously described approaches to address some of their limitations. In particular, the authors justify the need for an additional approach by stating that the combination and synthesis of the strengths of each of other approaches will allow AASP to better address the shortcomings of airport strategic planning. Hence, AASP borrows the concept of Real Options from APM and the notions of proactive planning, robustness, and contingency planning from FP to integrate them into the process described in Figure 29. Additional details regarding this process can be found in [193].

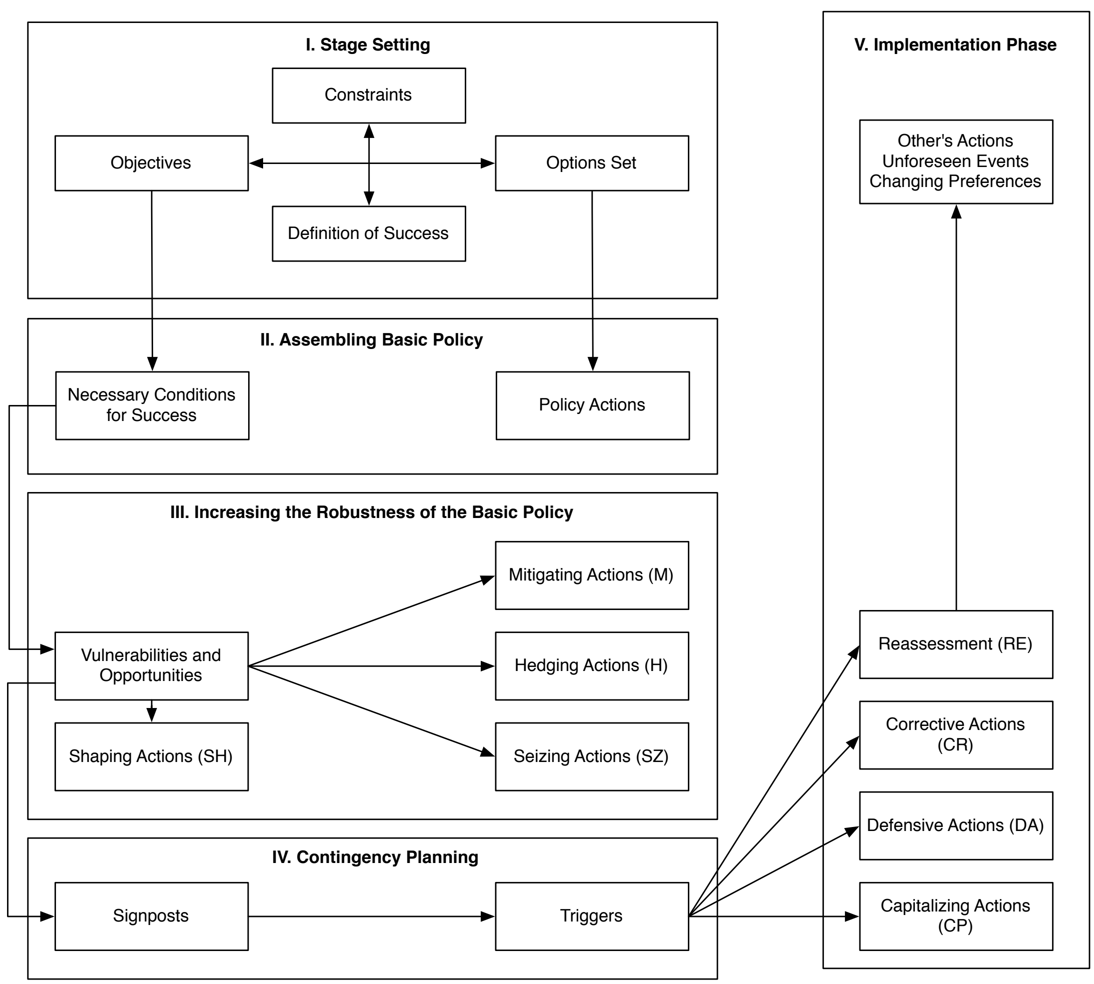


Figure 29: The steps of adaptive airport strategic planning [193].

Following a discussion on the applicability of this process at Schiphol Airport, the authors then conclude that AASP represents an improvement over the three separate approaches. Such a statement is difficult to make in light of what has been proposed and described in their paper [193]. It may appear justified from a methodological perspective (the proposed approach is coherent and, according to the authors, meets the predefined criteria for a successful planning approach), but is only true if the criteria defined are the appropriate ones. For example, the first criterion to be met by an alternative approach, as defined by the authors, is that "the planning approach should consider many different types of uncertainties, in addition to demand uncertainties"[193]. While it cannot be argued that considering more than one type or source of uncertainty will improve the way airport strategic planning is conducted today, the number of uncertainties that should be considered is irrelevant if the impact of these uncertainties on the system cannot be fully captured. In other words, the successful development of strategies to reduce the impacts of uncertainty and change require an understanding of how the system behaves. So, while AASP offers more capabilities in a more coherent and structured framework, it lacks, as the previously discussed approaches, the necessary and indispensable integration of the inherent dynamic and systemic complexity of the airport system in the planning framework.

2.7.3 Observation

Airport strategic planning with its reliance on a single demand forecast and focus on describing a single future long-range vision fails to provide airport managers with the policies and opportunities that would ensure airports' viability in the future. As stated by Heijden [318], "it is dangerous to plan strategically without being fully aware of the level of uncertainty facing the business".

The recent emergence of alternatives to airport strategic planning demonstrates the need for the definition and development of plans and policies that are flexible, and account for different types of uncertainties and plausible futures. However, while this new generation of airport planning approaches are taking airport strategic planning in the right direction, most of them are mainly qualitative and relatively conceptual. Additionally, lot of questions remain regarding their implementation (time and cost) and acceptance by airport stakeholders.

From Spitz' statement [277], it is clear that there was a need to change the way airport planners and stakeholders deal with uncertainties. The proposed approaches emphasize the need to consider various types of uncertainties and develop strategies to reduce the impacts of uncertainty and change. However, these approaches fail to recognize that the definition of such strategies first requires that the impact of these uncertainties be captured, which in turn requires that the dynamic structure of the airport system be considered and understood.

As a matter of fact, one of the sources of uncertainty often neglected, though very important to consider, is the lack of understanding of the complex environment [318], its structure [203], and its behavior. Airport strategic planning has often fell short of its goals because it has failed to comprehend the whole system perspective and structure, and recognize that the factors affecting airports, and the air transportation system as a whole, are in a constant state of flux. Consequently, there is a lack of analysis regarding how the airport system respond to these factors and the circumstances that drive the need for airport expansion. This leads to the following Research Question:

Research Question 2: How can the need for capacity expansion and resulting technology investments be identified and characterized?

Interestingly, as already mentioned, none of the recent alternatives that have been proposed to enhance airport strategic planning are fully capturing and integrating the inherent dynamic and systemic complexity and structure characterizing airports. The following section offers a brief discussion on these aspects and further describes them in the context of the airport and air transportation system.

2.8 Capturing the Dynamics of the System

Many forces, as discussed in Section 1.6, drive the Air Transportation and airport systems, making the contextual setting in which airports operate today relatively unstable and transitory [324]. However, the systems' response to these forces and their resulting behavior cannot only be determined by knowing the elements they are composed of, or the forces that are acting upon them. As stated by Meadows [217], "a system is more than the sum of its parts - it may exhibit adaptive, dynamic, goal-seeking, self-preserving, and sometimes evolutionary behavior." Forrester [128] makes the same argument: "Something about the structure of a system determines what happens beyond just the sum of individual objectives and actions." Along the same lines, Lyneis [203] emphasizes that "in many industries, behavior is determined more by industry structure than by changes in exogenous, macroeconomic factors."

The air transportation and airport systems are also characterized by long delays between causes and effects. These long time intervals between action and feedback, described as dynamic complexity [283, 154], prevent the conditions and parameters under which the air transportation system operates from being accurately predicted over significant periods of time. Many like De Neufville [71] have proposed to consider "both the ranges of the key parameters and the likely distribution of values of each important parameter over that range" as a way to mitigate this issue. In particular, De Neufville suggested to do so by consulting the historical record of fluctuations as well as by obtaining "expert opinion either directly or through the range of estimates available in the literature" [71]. While this represents an interesting approach to the issue, it has been recognized that judgmental adjustments to econometric forecasts lack the necessary rigor and consistency [203]. As a matter of fact, one can argue that historical records of fluctuation can be broken, and/or that other factors may come into play, with consequences on the overall system, and/or the range of other parameters, that even the best experts may not have foreseen. As emphasized by Lyneis [203], “industry forecasting models have not done a good job of forecasting because these models do not capture the structure of the industry which creates behavior over time.” Hence, as illustrated by the recent failures in airport planning, the lengthy time intervals between causes and effects, along with the resulting inability to comprehend or assess the impact of decisions, have often resulted in actions leading to unexpected consequences.

Finally, it is important to recognize that the multi-directionality and dynamic complexity of the causal relationships that characterize these systems cannot be captured, mapped or handled using mental models only [128, 283]. In particular, the various forces, elements, and parameters involved in such complex systems, along with their interrelations, make it impossible, with a mental model or expertise alone, to fully comprehend how systems work or may behave should a change occur. The reliance of mental models on incomplete, unclear or contradictory assumptions also prevent them from capturing the underlying systems' structure and implicit behavior [128]. The sole use of mental models thus often leads to poor decision-making [203].

To conclude, sound investment decisions regarding the development of secondary and underutililized airports require a good appreciation of the structure and dynamics of the Air Transportation and airport systems. It is thus paramount to:

- Understand the impacts that the air transportation system's behavior has on airports and vice versa: studying the consequences of uncertainty as a basis for decision-making, as it has been done in the past, is not sufficient

- Qualitatively and quantitatively assess the consequences and influences that future developments and investment decisions may have on both the air transportation system and airport dynamics [195]: the acknowledgment of a need cannot and should not, alone, trigger an investment decision

A well-known approach exists that addresses these two aspects and supports decision-making in the face of change. This approach, along with existing work describing its applicability to the problem at hand, is discussed below.

2.8.1 System Dynamics (SD)

Jay W. Forrester first developed industrial dynamics, the precursor of system dynamics, in 1955 to support the corporate understanding of industrial processes [291]. Industrial dynamics, as defined in the preface of his first book on the topic, "is a way of studying the behavior of industrial systems to show how policies, decisions, structure, and delays are interrelated to influence growth and stability" [127]. System dynamics is based on the underlying observation that the behavior of systems is the result of flows and stocks governed by balancing and feedback mechanisms [154, 217, 283]. The structure and rules of a system dynamics model thus build on identified explicit causal relationships and closed-loop feedback mechanisms that are represented by an interdependent set of nonlinear ordinary differential and algebraic equations [283]. These equations, derived from both measured data and experiential information [154, 68], describe the physical nature of the relationships between the variables of the model [68]. As explained by D'Avino [68] or Abbas [3], most of the variables of a system dynamics model are "generated and affected endogenously by the system structure itself. As a consequence, the resulting model is able to simulate a complex and non-linear behavior" [68]. Endogenous variables represent the flows and stocks in the system. They describe the behavior of the system if no external forces (exogenous variables) are perturbing it. System dynamics derives from feedback control theory, system theory, organizational theory, information science, cybernetics, tactical decision-making, and military games [3]. More particularly, it uses concepts and methods drawn from the fields of control theory and feedback analysis to provide a holistic view of a system of interest [211], and help understand [126, 283], analyze, or correct, the behavior of such complex systems [128, 68]. As stated by Forrester, "system dynamics provides a common foundation that can be applied wherever we want to understand and influence how things change through time" [128]. The use of system dynamics models, as emphasized by Lyneis [203], also allows for the quick identification of the variables or factors that influence the system, and thus decision-making, the most. It also supports the development and testing of alternative scenarios or structural assumptions [3]. System dynamics has thus widely been used to support effective strategic decision-making in the face of uncertainty [211], capture interdependencies and trade-offs [211], study the emergence of phenomena, understand the causes of industry behavior [203], assess the impact of decisions and alternatives on a system [283, 68], and determine scenarios of interest for policy/strategy evaluation [203]. It has repeatedly and successfully been applied to a wide range of problems and disciplines [282], such as public policy [129], strategic planning [204], supply chain management [10], and numerous models have been developed to address challenges in the fields of energy [235], biology [67], public health [154], socio-economic sciences [129], transportation [3], and various others. In particular, previous studies have shown that the dynamic complexity of the air transportation system, and airports in particular, as well as the non-linearity of their behavior (hysteresis in demand, financial constraints, time delays, etc.), can also be successfully addressed by the systems modeling methodology of system dynamics. The following section illustrates the use of system dynamics in air transportation studies.

2.8.1.1 The Use of System Dynamics in Air Transportation

This section presents a review of the most recent and relevant studies that applied the systems modeling methodology of system dynamics to air transportation related problems.

Lyneis [203], for example, developed a system dynamics model of the commercial jet aircraft industry to study the causes of cycles in the aircraft manufacturing industry, identify the external factors that influence the dynamics and structural changes in the industry, and support decisions regarding the introduction of new generations of aircraft. In particular, in his paper, Lyneis discusses and emphasizes that "system dynamics models can provide better forecast than traditional approaches." He also praises the use of system dynamics for forecasting to allow decision-makers to discover industry structural changes early on, identify important factors and scenarios of interest, and decide on buffers and contingencies that account for uncertainty and inaccuracies in the forecast.

In a related paper, Boeri [32] used system dynamics to model aircraft purchases by airlines. In particular, he modeled aircraft purchase decisions to determine the composition of future airline fleets and their impact on the behavior of the airline market.

Manataki and Zografos assessed the performance of the Athens International Airport's passenger terminal using a system dynamics model. In particular, they studied the impact of alternative demand [210, 209, 211] and resource deployment scenarios [211] on airport terminal operations. Their system dynamics model was used to explore what-if scenarios, and support "airport decision-makers in airport terminal planning and operations" by focusing on performance metrics such as capacity, delays/waiting times, level of service, resource utilization, etc. [211, 210].

Galvin [133] developed a system dynamic model to study and investigate the impact that the Small Aircraft Transportation System (SATS) may have upon the dynamic behavior of a future Air Traffic Control (ATC) system represented by different radar and GPS-based architectures. In particular, he tested different ATC resource management strategies that had the potential to support the future needs of SATS aircraft in the system and bring sufficient money from tax revenue to fund the Federal Aviation Administration (FAA). Galvin claimed that his model helped increase the understanding of the impact that SATS aircraft may have in the dynamics of a future ATC system, while providing insight into the effects of feedback between the Airport and Airway Trust Fund (AATF) and the ATC system.

Bonnefoy and Hansman [35, 37] developed a System Dynamics model of a regional airport system to study the impact of different factors on the airport systems dynamic. In addition, they built a System Dynamics model coupling multiple airports to capture the impact of the performance of an airport on other regional airports. The models are articulated around a stock and flow diagram that starts with the demand for air transportation and four causal loops (airport growth, demand stimulation, airport congestion, and capacity adjustment), which captures the core dynamics of system.

Abad and Clarke [2] presented a system dynamics model to support the determination of optimum portfolios of airspace infrastructure investments for NAS modernization. The model represents a generic R&D project, includes three feedback loops (Efficiency, Performance, and Progress) but does not detail any variables, outputs or relevant relationships.

Suryani et al. [287] developed a system dynamics model to study the future need for additional runway and passenger terminal capacity at Taiwan Toyuan International Airport. They concluded that the airfare impact, level of service impact, Growth Domestic Product (GDP), population, number of flights per day, and dwell time were important factors to consider when assessing air passenger volume, runway utilization, and the ability of passenger terminals to accommodate future demand.

Miller and Clarke [222] developed a system dynamics model to help validate the hypothesis that the coupling of internal market dynamics projects to external dynamics contribute to the strategic value of air transportation infrastructure. They studied the hypothetical situation where a new single runway airport was considering building a second runway on a newly acquired adjacent piece of land. In their work, a System Dynamics model was built to capture the dynamics of the system under airport management's decisions. This model included multiple sources of uncertainty and feedback loops. The information obtained from it (expected revenues from travel demand served by the second runway, and costs of infrastructure expansion and maintenance) was then used to support the decision of whether or not to build a second runway. In a different study, Miller and Clarke [225] used the system dynamics model described above to study the infrastructure delivery problem. Hence, they defined different strategies for aviation infrastructure delivery and evaluated the benefits from reacting quickly to variations in the market. Each strategy was defined in terms of the amount of capacity increase, the time to deliver the capacity, and the congestion threshold that called for additional capacity. The main outputs of the model were, similarly to the previous study, airport revenues and cost of infrastructure construction and maintenance. Those were then used to compute the net present value of each infrastructure delivery strategy. Finally, Miller and Clarke [224] again used the same system dynamics in a Real Options Analysis (ROA) framework to analyze three flexible capacity expansion strategies, and assess the variation in the value of the flexibility. Their infrastructure delivery strategies were defined in terms of "the maturity of the option, the size of the capacity expansion, and the time to deliver the capacity once the decision to expand has been made" [224]. In particular, they showed that small capacity expansion projects are more likely to succeed, and that a short response time in the delivery of needed capacity is key. They also concluded that a long maturity date is preferable in the case of large capacity increase projects. Finally, they noted that flexibility becomes valuable for large capacity expansion projects facing large amounts of uncertainty.

The aforementioned studies using system dynamics to address questions and challenges related to the air transportation industry are categorized below (Table 13).

Table 13: Categorization of past air transportation studies' topics using system dynamics

Subject	Studies
Identification and assessment of key factors' impacts on the dynamics of the system of interest	[203, 32, 133, 35, 37, 287]
Infrastructure expansion	[287, 222, 224, 225]
Aviation resource management	[32, 287]
Assessment of performance improvements resulting from various decisions or strategic investment scenarios	[203, 32, 210, 209, 211, 133, 2, 222, 224, 225]

2.8.2 Observation

As discussed in Section 2.7, the airport expansion projects that failed, mainly did so because they were based on mental models, statistical forecasting models and/or judgmental/empirical adjustments to econometric forecasts. They were lacking or ignoring the impact that airports have on their environments, and vice versa. While the use of assumptions and predictions about future demand and performance is inevitable, a proper understanding and representation of the complex dynamics and structure involved are essential [203]. It has been shown that System Dynamics provides a more holistic, structured and rigorous view of a system than the biased or incomplete mental models commonly used by decision-makers or analysts. It has also been recognized that the structural aspect of system dynamics models "can provide more reliable forecasts of short- to mid-term trends than statistical models, and thus lead to better decisions" [203]. System Dynamics has been shown to be well suited to address the dynamic complexity of the air transportation system, and airports in particular, as well as the non-linearity (hysteresis in demand, etc.) and time delays of their behavior. As it provides insight into the short- and long-term behavior of the system, it enables the planning, and evaluation of timely improvements or changes to the system [3]. Hence, System Dynamics has proven to be very valuable in dealing with questions regarding infrastructure expansion, aviation resource management, and the assessment of performance improvements resulting from different strategic investment scenarios.

As a conclusion to this discussion, the diversity of the air transportation issues addressed by System Dynamics and presented above demonstrates that System Dynamics is particularly well suited to tackle the challenges associated with the nature of this research. Hence, the systems modeling methodology of system dynamics will be implemented to **identify the key variables and factors that have the biggest impacts on airport's performance.** The associated hypothesis can therefore be formulated:

Hypothesis 2: System dynamic modeling provides a means to identify the key factors driving the need for capacity expansion, and the resulting technology investments

The knowledge gained from capturing the changes in the system is essential but only valuable if integrated into the definition and selection of technology portfolios. In other words, technology portfolios should be defined in a way such that they can address change. This brings us back to the third assertion made in Chapter 1:

ASSERTION 3: Incorporating and maintaining the capability to adapt to continuing changes when planning for the development and expansion of secondary and currently underutilized airports is essential to ensure the financial sustainability of their investment decisions

The following section discusses this assertion.

2.9 Integrating the Capability to Adapt into the Definition of Technology Portfolios:

The literature is replete with papers discussing approaches to cope with unpredictable environments. The following paragraphs discuss two main strategies, namely Robustness and Flexibility, and their applicability in the context of this work.

Because robustness and flexibility commonly refer to the ability of a system to handle change and deal with uncertainty, both terms have been used interchangeably in the past. Hence, many definitions have been provided that failed to distinguish between these two concepts. Gupta et al. [146], for example, would define both robustness and flexibility of a decision as "the number of the "good" end-states for expected external conditions which remain as open options." In reality, as pointed by Saleh et al. [265, 264], their applicability differs with respect to the nature of the change and the system's reaction to it (Figure 30).

- **The Robust strategy or "The Good Compromise":** The most comprehensive and accurate definition of robustness is provided by Saleh et al.: "Robustness [...] is the property of a system that allows it to satisfy a *fixed* set of requirements, *despite* changes in the environment or within the system (or noise factors)" [265]. Hence, it involves the formulation of alternative futures and the selection of solutions or options which provide the best performance independently of the scenarios considered [191, 21]. Robustness thus only addresses changes in the environment. Although valuable, this approach is also limited, at the time of the analysis, by the range of scenarios considered and by the number of options currently known or expected in the near future [191].

- **The Flexible strategy or "The Room for Growth":** Embedding flexibility in a system or process has also been identified as a way to cope with uncertainty and change. However, there are probably as many definitions of the word "flexibility" as there are disciplines or fields of study [265]. A definition of flexibility in the published literature [265, 264] is "a property of a system that allows it to respond to changes in its initial objectives and requirements - both in terms of capabilities or attributes - occurring after the system has been fielded, in a timely and cost-effective way." Stated differently, the flexibility of a system is "its ability to meet a changing set of requirements after it has been fielded under new modes of use or changes in its environment" [21]. In particular Saleh et al. [265] noted that, "flexibility should be sought when the uncertainties in a system's environment are such, that there is a need to evolve the system after it has been fielded in order to mitigate market/environment risks, and when the system's technology base evolves on time scales considerably shorter than the system's design lifetime [...]." A flexible system should thus be able to handle changes at *both* the requirements and environment levels.

Figure 30 summarizes the difference between robustness and flexibility in terms of their ability to handle changes in a system's requirements and environment. These differences can also be illustrated by looking at the ability of a robust and a flexible system to meet requirements at different points in time (Figure 31). It can be seen that, while a robust system will perform consistently under various conditions, it will not be able to account for changes in the system's requirements. A flexible system, on the other hand, is expected to adapt and close the gap.

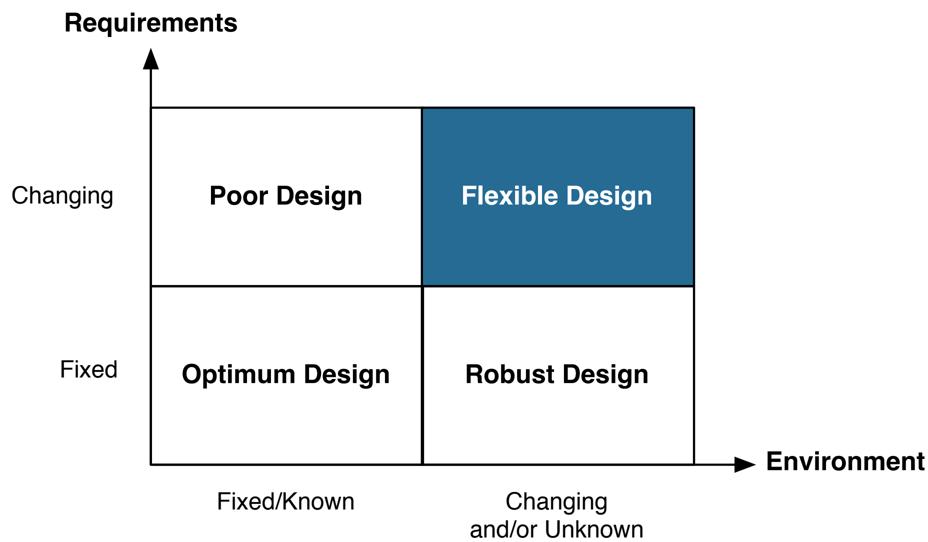
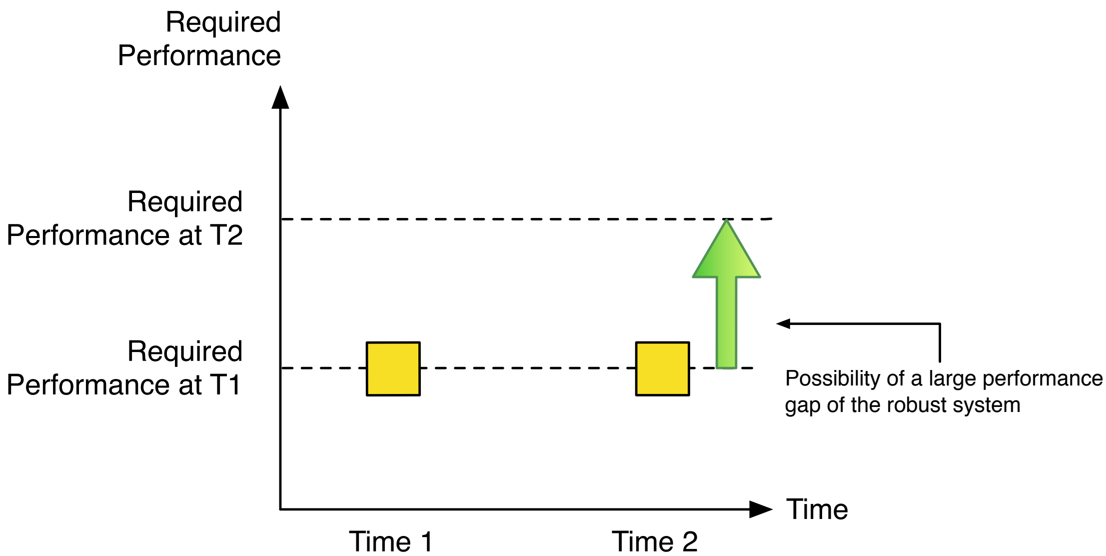
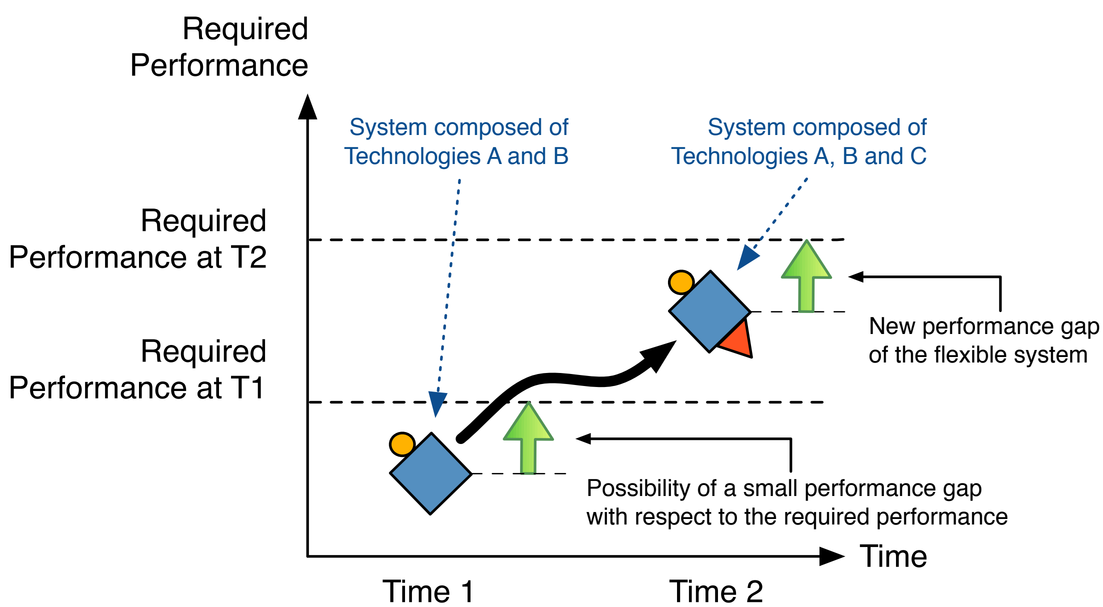


Figure 30: Flexibility and robustness as a function of the system's requirements and environment (adapted from [264]).

In our context, it is very likely that the environment in which airports operate will change over the years. These changes (change in demand, traffic mix, etc.) will not be without consequences on the airport requirements. For example, the implementation and reinforcement of environmental policies and regulations may force the proliferation of new types of air vehicles. These new vehicles may not have pilots on board, thus requiring the installation of new technologies in the cockpit. These technologies may, in turn, require that new functionalities be created and added to existing on-ground equipment. Similarly, an increase in air travel demand would force bigger aircraft, or an increasing number of



(a) Robust System.



(b) Flexible System.

Figure 31: System evolution and resulting performance gaps after a change in the required performance (adapted from [265]).

smaller aircraft, to operate at airports. Depending on the strategies followed by airlines, new requirements in terms of technology performance and functionalities (be able to track aircraft on the ground, reduce separation, etc.) will likely be necessary in order for airports to accommodate this new types of traffic.

In light of these two examples, it appears that a robust strategy may not be the most appropriate one to follow. Indeed, because airport performance and requirements will likely evolve as the air transportation system undergoes changes, a portfolio which meets today's requirements independently of future changes in the system might quickly become obsolete (Figure 31). It thus appears evident that a flexible strategy is preferable.

The need to plan and design systems or products which are flexible in nature is not new and has already been advocated in the literature [265, 264, 21, 191, 146, 183, 65, 229, 212]. Hence, as stated by Saleh et al. [264], "flexibility is a key property that should be embedded in high-value assets, particularly as they are being designed for increasingly longer design lifetimes." In particular, the need to embed flexibility in airport development plans to deal effectively with a range of futures has already been recognized as essential [194, 74, 71, 207]. De Neufville [71] and Karlsson [183], for example, attributed the failure of many airport development and long-term planning projects to the lack of consideration for risk and uncertainty into the process, as well as the omission to incorporate flexibility to deal with these risks. Karlsson also emphasized that "flexible planning is a must" [183] for newly constructed commercial airports, or existing airports with low levels of traffic, because these airports have little knowledge regarding the nature, attributes, and time-horizon of future demand and traffic. Hence, there is a strong belief in the air transportation community that strategic value, in other words value gained from being able to address a wide range of futures, could be gained from embedding flexibility in the planning and investment process.

This important observation leads to the following Research Questions:

Research Question 3.1: How do we define and embed flexibility in the formulation of technology portfolios so as to answer airport future requirements and provide financially viable solutions?

Research Question 3.2: What is the strategic value, for airports, of embedding flexibility in the formulation of technology portfolios?

A proper answer to these questions cannot be provided without characterizing beforehand the two concepts embedded in these questions. The following sections thus further define and investigate the concepts of flexibility and value to guide the formulation of hypotheses aimed at addressing the aforementioned questions.

2.9.1 Characterization of Flexibility

Addressing these questions first requires that the concept of flexibility be further defined and discussed. While flexibility in airport planning has been commonly recognized as "the possibility of changing the course of actions and ultimate development of the airport according to the realization of future events" [207], a more specific definition of the term *flexibility* in the context of this research is needed.

As previously discussed, there is a need to define technology portfolios capable of evolving to respond to changes in requirements occurring after they have been acquired and/or deployed, and this, in a timely and cost-effective manner. In other words, the capability of a portfolio to change after it has been deployed should be embedded in its initial formulation. Deciding to invest in a subset of technologies may help airports reduce their financial exposure and prevent them from making potentially unprofitable commitments, while still allowing them to grow and gain more information about the future. As the future unfolds, airports may then decide to expand their technology portfolio, or maintain it.

A similar model is described by Cyert et al. [66]. Due to the fact that most of the technologies considered are interdependent, as discussed in Section 2.1, investing in a subset of technologies may still provide airports with opportunities to expand their portfolio and help them meet their future requirements. Attention must be paid, however, to the formulation of the initial portfolio, to ensure that the technologies already in place are accounted for.

It is also important to recall that airports are subjected to changes, not only at the system level, but at the management level as well. Decisions that may have been agreed upon in the past, may be revisited or even cancelled by a new management team or governing entity. Hence, it is essential that the approach proposed for technology portfolio investment and the formulation of the technology portfolio itself enables and supports managerial flexibility. In particular, the interdependence of investment decisions [146] requires that technology portfolios be flexible, i.e, that they also provide a future management team with more options than just pursuing or canceling the vision of its predecessors. Hence, airport managers should have some flexibility at the decision level as well, meaning that they should be able to defer their decisions or modify them once they have a better understanding of how the situation may develop. Consequently, flexibility, in the context of this research, will be defined at two levels:

- At the system level, flexibility represents *the capability of a portfolio to evolve to respond to changes in requirements occurring after it has been acquired and/or deployed, and this, in a timely and cost-effective manner*. In particular, flexibility will represent the capability to add technologies from an initial portfolio formulation to be able to fulfill different functional requirements at different points in time (Figure 31(b)).

- At the management level, flexibility represents *the capability to implement mid-course strategy corrections as the future unfolds and some of the uncertainty gets resolved.*

While there is a common agreement that embedding and maintaining flexibly in the planning and investment process is essential, little has been said on how to operationalize or embed flexibility in the context of airports. This leads to the following Hypothesis:

Hypothesis 3.1: The implementation of sequential, or staged, investment decisions, on which airports can decide to leverage earlier investments, will allow airports to meet their future requirements and provide them with financially viable solutions.

A means to embed and maintain flexibility in the planning and investment process has just been proposed. However, a way to capture the value of flexibility remains to be suggested. The following section thus discuss the concept of value, and further details and evaluates value-centric methods to technology acquisition.

2.9.2 Value and Value-Centric Methods to Technology Acquisition

As claimed by Stigler [284], "flexibility is not a free good", and often results in costs and other penalties [265, 21]. However, flexibility, as argued in Section 2.9.1, also provides additional value to investments. This value is often represented by the long-term, strategic, and follow-up growth opportunities associated with a new investment. As emphasized by Keeney [185],

> "rarely is one decision completely uncoupled from other decisions. Choices today affect both the alternatives available in the future and the desirability of those alternatives. Indeed, many of our present choices are important because of the options they open or close or the information they provide rather than because of their direct consequences."

However, quantifying such value is an arduous task. In this respect the following section proposes a review of the most prominent valuation techniques, and discusses their use and applicability to the problem at hand.

2.9.2.1 Discounted Cash Flow and Net Present Value Rule

Discounted Cash Flow (DCF) evaluates an investment by estimating the present value of future cash flows. It is based on the notion that, because the future is uncertain, money today is worth more than money tomorrow (the time value of money) [39]. DCF is a consistent method that has been used in a variety of valuation methods. In particular, DCF is used to compute the Net Present Value (NPV) to estimate the profitability of an investment opportunity. The NPV rule was first clearly identified in the 1950s [226]. However, its origins go back to Irving Fischer [124], who first proposed in 1907, to "discount the expected cash flow at a rate that best depicts the risk associated with the project" [39]. In particular, the NPV rule helps decision-makers determine if a project will be profitable by looking at the difference between the present value of the investment (the cost of implementing the project, or required capital expenditure) and today's value of future cash flows that the project is expected to generate (future net free cash flows) [232] (Equation 2).

$$NPV = \sum \text{PV of benefits - PV Investment Cost} \tag{2}$$

The investment decision is thus based on information that is currently available to the decision-maker. The rule also says that if the NPV is positive, then managers should go ahead and invest, otherwise they should abstain from making the investment [202]. Similarly, in the case where many projects are competing for funding, the one with the highest NPV should be chosen. Although this approach is straightforward [83], it is nonetheless built on faulty assumptions, as discussed below.

Drawbacks and Limitations of Net Present Value:

One of the fallacies of the NPV approach is to assume that the cash flows are certain [39], that they occur at fixed points in time [224], that investments are isolated opportunities [267], and that there is only one possible course of action, the "now-or-never-proposition"

[83, 276]. Such assumptions fail to realize that, in reality, investments can be delayed and that new information can be gained that might influence the profitability and change the original timing of the investment plan [83, 222, 39, 232, 276, 267]. Consequently, NPV cannot explicitly integrate managerial flexibility and the changes in the schedule of cash flows that may result from it [224]. As such, “traditional NPV misses the extra value associated with deferral because it assumes the decision cannot be put off” [202].

NPV can also lead to wrong investment decisions if the uncertainty associated with future cash flows and risk has not been captured properly. As explained by Brathwaite and Saleh [41], and Mun [232], deterministic calculations of NPV can underestimate the value of a project. In particular, they may induce errors in decision-makers’ judgements when cash flows cannot be accurately projected and when the risk associated with the project is uncertain. A way to remedy this issue, as suggested by many [41, 83, 224], would consist in running Monte Carlo simulations on the various inputs subject to uncertainty. This would provide a probability density function of the NPV which would better inform the decision-makers of the value and risk of the investment.

Finally, another limitation of the NPV rule is that it ignores the value of creating options [83] and that of flexibility [39]. As emphasized by Dixit and Pindyck [83],

> “sometimes an investment that appears uneconomical when viewed in isolation may, in fact, create options that enable the company to undertake other investments in the future, should market conditions turn favorable”

In other words, because the NPV approach ignores these aspects, it does not provide a comprehensive view of the value of an investment [232], but only the value related to its cost [212]. Hence, by doing so, it ignores valuable follow-on investment projects and thus underestimates the true economic value of an investment [267]. In face of all these limitations, Miller [226] advises to use DCF and NPV only “for decision involving a moderately straightforward business structure, unsophisticated projects, and a steady environment that allows for dependable forecasts."

2.9.2.2 Decision Analysis

Decision Analysis is a popular investment evaluation technique founded on the concepts of subjective probability and utility [185]. It has been defined by Keeney [185] as "a philosophy, articulated by a set of logical axioms, and a methodology and collection of systematic procedures, based upon those axioms, for responsibly analyzing the complexities inherent in decision problems." In other words, DA provides a clearly structured, transparent, and systematic method that first allows to capture the decision-maker's subjective judgement, choices, and preferences regarding a decision problem [156], and then helps define an optimal decision in face of the uncertain and dynamics characteristics of that problem [71, 156, 185, 183]. This iterative and interactive process has been extensively implemented in a variety of problems and contexts. Its structure is composed of four steps, with steps 1 to 3 representing the greatest portion of the overall effort [185, 156]:

- Step 1 - Structure the decision problem:

  This step strongly encourages and structures the creative thinking of the decision-maker to generate alternatives, and specify objectives. Those alternatives are formulated by first defining what the initial action should be and then enunciating which further actions should be chosen given following events. A decision tree is often used to represent the breadth and depth of alternatives generated (the decision set)

- Step 2 - Assess possible impacts of each alternative:

  A set of possible consequences along with the probability (likelihood) of each occurring is determined for each alternative. The case of conditional dependencies (when two alternatives are probabilistically dependent) may be problematic and requires additional effort to characterize them

- Step 3 - Determine preferences (values) of decision-makers:

  This is accomplished through the formulation of a utility function that elicits and quantifies professional and value judgments about potential consequences and implications. The utility function indicates the desirability of a consequence relative to all other consequences

- Step 4 - Evaluate and compare alternatives:

  The expected utility of each alternative is computed and the alternative with the highest expected utility is ranked as the most desirable one or optimal choice [183]

DA has been recognized as an improved version of DCF or NPV [305] because, by assigning probabilities to various alternatives at certain points in time, it actually allows some flexibility into the decision framework [9]. It has also been perceived as a useful approach "for analyzing complex sequential investment decisions" [305]. However, this technique, as with any other, presents some shortcomings.

Drawbacks and Limitations of Decision Analysis:

One of the drawbacks attributed to Decision Analysis is that it is too subjective and value-laden [185]. In short, some detractors of this method point out the heuristic and judgmental biases that may affect the value of the analysis. As emphasized by Howard [156], "as the degree of uncertainty goes up, experimental subjects begin to form false hypotheses and to retain them in the face of contrary evidence. It is a case of 'the burned cat fears the hot stove - and the cold one', too." Hence, the quality of the analysis depends highly on the quality of the decision analyst [185]. Another limitation mentioned in the literature is the lack of consideration for the perspectives of other stakeholders in the development of the analysis [74]. Concerns also exist regarding the ability of Decision Analysis to handle multiple sources of uncertainty [222]. The fact that decision-makers are able to decide what alternative to follow as the future unfolds and uncertainties are resolved makes decision analysis a candidate method for the valuation of flexibility. However, its reliance on a decision tree to represent the structure of the alternatives and their outcomes may limit the number of alternatives, and thus uncertainties, that can be considered. Hence, as the number of decisions and alternatives increase, the decision tree expands geometrically and quickly becomes too large to be manageable or insightful [304]. Other concerns arise regarding the method's lack of procedures to value flexibility and provide the solution that maximizes the value of investments [74]. Finally, from an implementation standpoint, others have stressed its weakness or lack of logical/theoretical grounds.

2.9.2.3 Real Option Analysis

Option theory concepts are first introduced to facilitate the reader's understanding of Real Options Analysis (ROA).

Option Theory Concepts

Since Myers' view [234] of discretionary investment opportunities as "growth options" in 1977 [270], Real Option Analysis (ROA) has grown into an increasingly well accepted [202] and promising valuation method for strategic corporate investment decisions [226] and business decision analysis as a whole [157]. ROA has its quantitative roots in financial options, and more particularly in the work of Black and Scholes [31], and Merton [220], who fathered, in 1973, a definition and formulation for the valuation of financial options [226, 270, 157]. However, the first account of an option trade goes back a few millenaries earlier, around 600 BC. Evidence was found in Aristotle's book, *Politics* [12], that Romans and Phoenicians used options contracts to ship goods across the Mediterranean [206]. In particular, Aristotle recounts in Book 1, Part XI of *Politics*, the story of Thales of Miletus (624-547 BC), who, in 600 BC, made agreements with all the olive-press owners of Miletus and Chios, and deposited money with them to secure the presses when the harvest was ready. Eventually, the harvest proved to be bountiful and Thales made a lot of money.

> "There is the anecdote of Thales the Milesian and his financial device, which involves a principle of universal application, but is attributed to him on account of his reputation for wisdom. He was reproached for his poverty, which was supposed to show that philosophy was of no use. According to the story, he knew by his skill in the stars while it was yet winter that there would be a great harvest of olives in the coming year; so, having a little money, he gave deposits for the use of all the olive-presses in Chios and Miletus, which he hired at a low price because no one bid against him. When the harvest-time came, and many were wanted all at once and of a sudden, he let them out at any rate which he pleased, and made a quantity of money. Thus, he showed the world that philosophers can easily be rich if they like, but that their ambition is of another sort. [12]"

The word *option* comes from the medieval French [39], and is derived from the Latin *optio*, which means *choice* [132]. In financial options, an option represents "the right, without an associated symmetric obligation, to buy (if a *call*), or sell (if a *put*) a specified asset (e.g., common stock) by paying a pre-specified price (the exercise or strike price) on or before a specified date (the expiration or maturity date)" [304]. In particular, an option is defined with respect to the five following variables [157, 202]:

- The stock price or underlying asset price: the net present value of the potential investment if the investment was happening today [157]
- The exercise price or strike price: the price at which the option owner can buy (*call* option) or sell (*put* option) the underlying asset [39]
- The expiration date or maturity date: the last day in which the option may be exercised. In particular an American option is an option that can be exercised at or anytime before maturity, as opposed to a European option, which is an option that can only be exercised at maturity [304]

- The risk-free interest rate: “the rate of interest the market is willing to pay on an asset whose payoffs are completely predictable” [157]

- The volatility or variance of returns on stock: it “measures how hard it will be to predict the underlying asset’s price into the future” [157]

In the case of a call option, a buyer of an option has the right to buy some stock (underlying asset) from the seller of the option for a certain price defined as the strike price X. He can do it at maturity (the expiration date) in the case of a European option, or anytime before or at maturity for an American option. To have this right, the buyer pays a call premium. The value of an option, or payoff function P, is, in the case of a call option (buy), the difference between the stock price S and the strike price X (Equation 3). The payoff function for a European call option is represented in Figure 32.

$$\text{P} = Max[\ 0, \text{S - X}\ ] \text{ or } \begin{cases} S - X \text{ if and only if } S > X \\ 0 \text{ if and only if } S \leqslant X \end{cases} \tag{3}$$

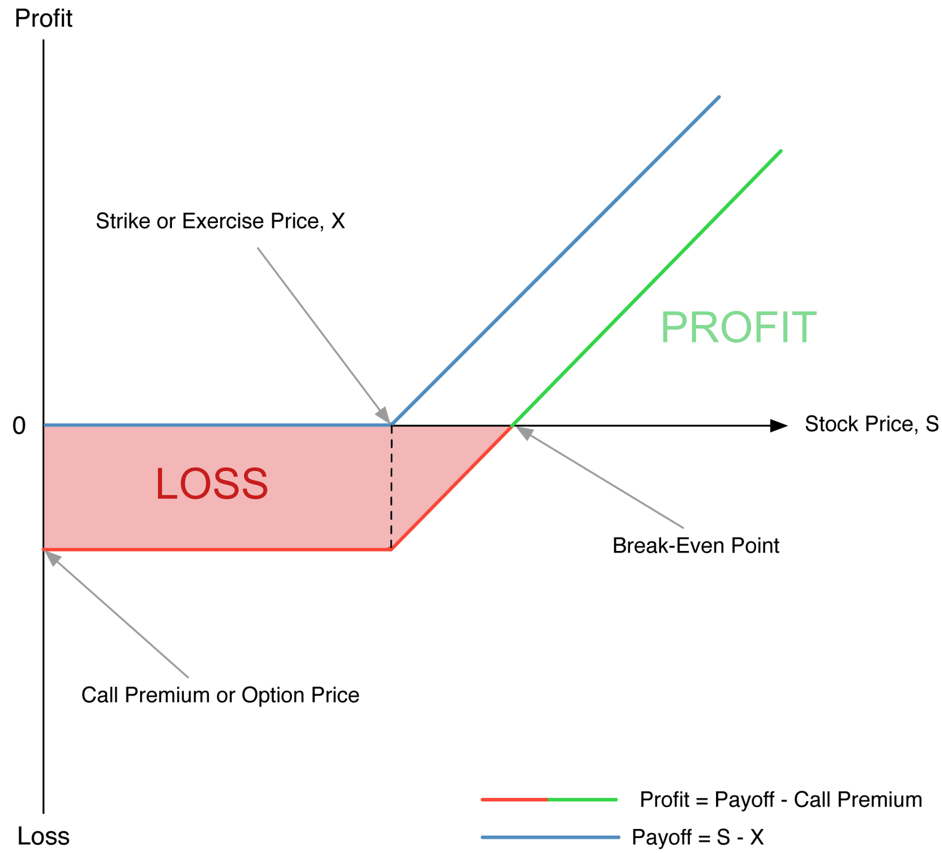


Figure 32: Profit and payoff at expiration for a call option.

Hence, as long as the stock price S is less than the strike price X, the payoff remains 0 and the buyer has no reason to exercise his option. The option is said to be out-of-the-money. In other words, if the stock price S remains below the strike price X until the expiration date, the owner of the option endures a loss corresponding to the call premium. In the case where the stock price S goes above the strike price X, the owner of the call option can buy the stock for X and then sell it for S. The payoff would then correspond to S-X. The option is said to be in-the-money. However, the owner of the option only starts making a net profit when the payoff is more than the premium paid for the option.

Let consider the case where the option can be exercised anytime before or at maturity (American option). A buyer buys 100 shares and pays a premium of $10/share. The strike price is $50. If the share price rises to $80, then the buyer can buy his 100 shares for $5000

(100*50) and sell them for $8000 (100*80). The payoff of this operation is thus $3000 (8000-5000). However, because the buyer has invested $1000 for the right to buy at a given strike price, his net profit is only $2000 (3000-1000). Now if the share price drops to $30, the buyer would not exercise his option, hence loosing the $1000 (10*100) corresponding to the premium for the option contract.

Future stock prices are uncertain, but some indication regarding their evolution can be gained by looking at the volatility of the stock movement. The volatility, as defined by Howell et al. [157], is "the speed at which the market value of the *underlying asset*[1] (the asset which we hold a *real call option* to buy, or a *put option* to sell) tends to diverge randomly away from (and around) today's value as time passes into the future." Hence, the higher the volatility of the stock movement, the faster the divergence from today's value, the more likely the value of the stock at maturity to exceed the exercise price, and thus the higher the payoff for the buyer of the option [39, 157]. Likewise, the value of an option is higher when the time to expiry is longer [157]. Additional factors that affect the value include the exercise price, the conditions of the market for the underlying asset, and the rate of interest on risk-free investments, i.e. "the rate of interest the market is willing to pay on an asset whose payoffs are completely predictable" [157].

The value of an option is composed of an intrinsic value and an extrinsic value (Figure 33). The intrinsic value corresponds to the payoff value at expiration, as described previously. The extrinsic value, also known as the time value, exhibits the following behavior: it is small when the stock price is far from the exercise price (far out of the money or deep-into-the-money), and maximum when the stock price is exactly at the exercise price (at the money). This trend can be explained by the fact that the behavior of the stock price in an efficient market is a random walk [157]. In other words, this means that at a particular instant, there is a 50 percent chance that the stock price will rise and a 50 percent chance that it will fall. Hence, on average, the best forecast corresponds to the current value. Now

[1] in italics in the text

consider the three following scenarios:

- Scenario 1: If the stock price is far out of the money, the likelihood that it surpasses the exercise price (and be in the money) on expiry is very low. In other words, the average of the likely future payoffs at expiration is close to zero. In this particular case, the option's time value is small: there is not much value in waiting since it is very likely that the option will not be exercised. The extrinsic value thus adds very little to the intrinsic value of 0

- Scenario 2: If the stock price is deep-in-the-money, the likelihood that it surpasses the exercise price on expiry is very high. Hence, once again, in this particular case, the option's time value is small: there is not much value in waiting since it is very likely that the option will be exercised. The extrinsic value thus adds very little to the intrinsic value

- Scenario 3: If the stock price is at the money, the likelihood that it will be in the money equals the likelihood that it will be out-of-the-money at expiration. Hence, there is much value in waiting since the doubt whether to invest or not, i.e. the uncertainty, is maximum at that moment. The extrinsic value is thus maximum

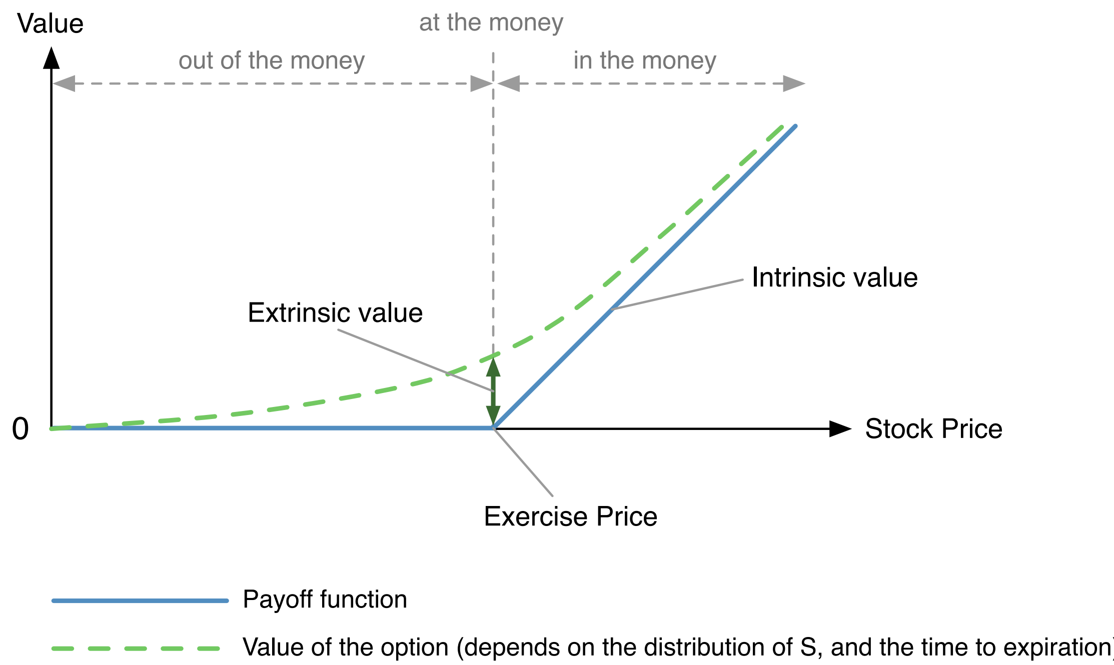


Figure 33: Intrinsic and time value of a call option.

Real Options Concept

Real options, as its name implies, is financial options theory applied to physical or real assets [232]. Hence, instead of addressing financial assets or stocks and bonds, real options is concerned with estimating the value of flexibility of "real" projects in face of uncertainty [232]. In fact, as stated by Smit and Trigeorgis, "the opportunity to invest in a project is analogous to having a call option" [276]. The correspondence between a project's characteristics and the variables that determine the value of simple call option on a share of stock is depicted in Figure 34.

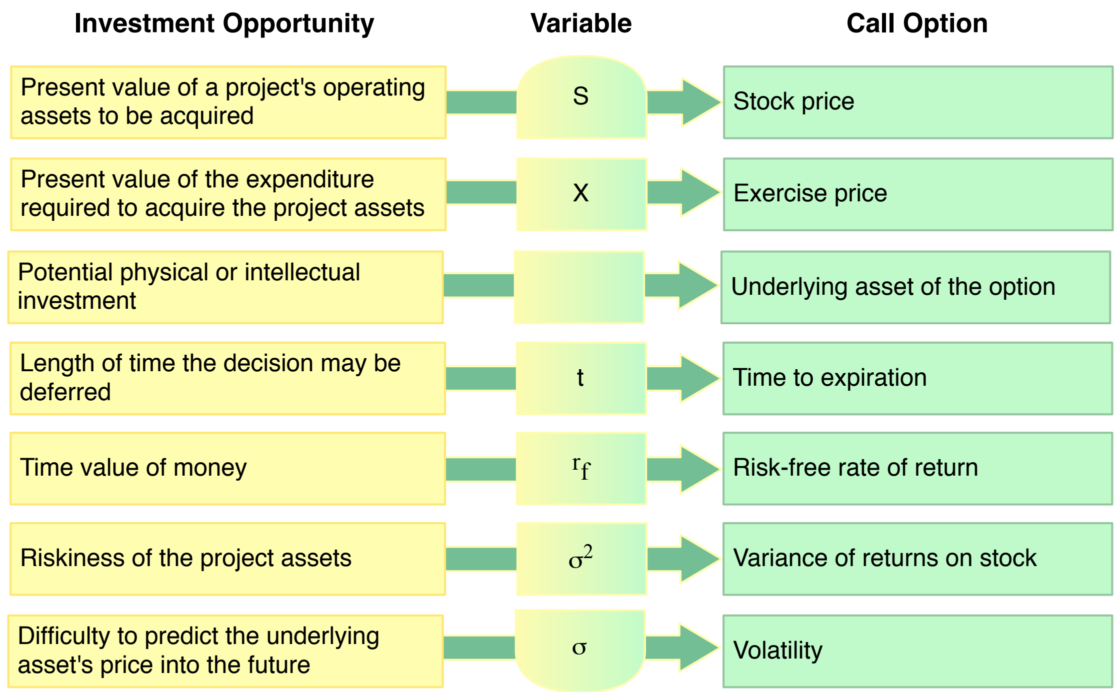


Figure 34: Mapping an investment opportunity onto a call option (adapted from [202] and [157]).

The key difference between financial and real options is that, while the decisions about financial options do not change a company's value, a wrong decision about real options will change a company's value and resources [157]. Additional differences between financial and real options theory exist and can be found for example, in Chapter 5 of Mun's book [232].

One of the strengths and values of Real Options is that it provides managerial flexibility, i.e, the opportunity to implement mid-course strategy corrections as the future unfolds and some of the uncertainty get resolved [232]. Hence, Real Options Analysis offers the options buyer multiple decision pathways he can chose from depending on the level of uncertainty faced. The most common types of options are described in Table 14.

In particular, the possibility to wait (option to defer) gives rise to two sources of value [202]. The first source of value is that by investing later rather than sooner, the investor

Table 14: Most common real options types

Real Options Type	Description
Exit and Abandonment	Exit options are interesting for projects that can be discarded and for which salvaged resources can be redeployed elsewhere [232]
Contract	Options to contract are interesting in competitive environments when they may be a need to downsize or outsource operations or resources as the market conditions change. In this respect, options to contract are very similar to put options [192]
Defer	Options to defer are interesting as long as their time value is above zero. The time to wait depends on the cost and the benefits associated with the delay [157]. These options are particularly valuable when the holder owns a particular resource (land, etc...) and can wait before deciding upon developing it. [304]
Growth	Growth options are interesting for projects that are interrelated as they can open up future growth opportunities. Such options are similar to project compound options [304]
Switch	Switch options are interesting when it is possible to switch between inputs (process flexibility) or between outputs (product flexibility). Such options are particularly valuable when there is a change in the market or the demand for a type of product [304, 157]

can earn the interest, or the time value of money [157], on the required capital expenditure. The second source of value corresponds to the fact that the value of the underlying asset is likely to change and that by waiting, the buyer will acquire valuable information, some of the uncertainty will be resolved, and he will more likely be able to obtain an optimum profitability [212]. Hence the value of a real option is divided into two components [276]:

- The traditional or passive net present value of an investment in an underlying asset, which is equivalent to the payoff function of a (financial) call option (as illustrated in Figure 35). In other words, this means that the option value and the NPV are the same when a decision on an investment cannot be deferred, i.e. at the time of expiration [202]

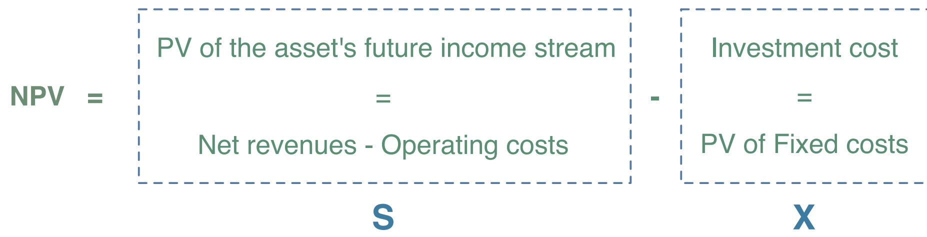


Figure 35: Similarities between the Net Present Value of an Investment and the Option Payoff Function.

- The value associated with being able to defer an investment decision, defined by Smit [276] as the "timing flexibility component." Similarly to financial options, the value of flexibility for real option is maximum when the option is at the money. In other words, the value of deferring an investment is the greatest when it is on the verge on being profitable (NPV of 0) [157]

These two components form the Expanded NPV criterion, or eNPV, illustrated in Figure and defined in Equation 4 as:

$$\text{Expanded NPV} = \text{Passive NPV} + \text{Flexibility Value} \tag{4}$$

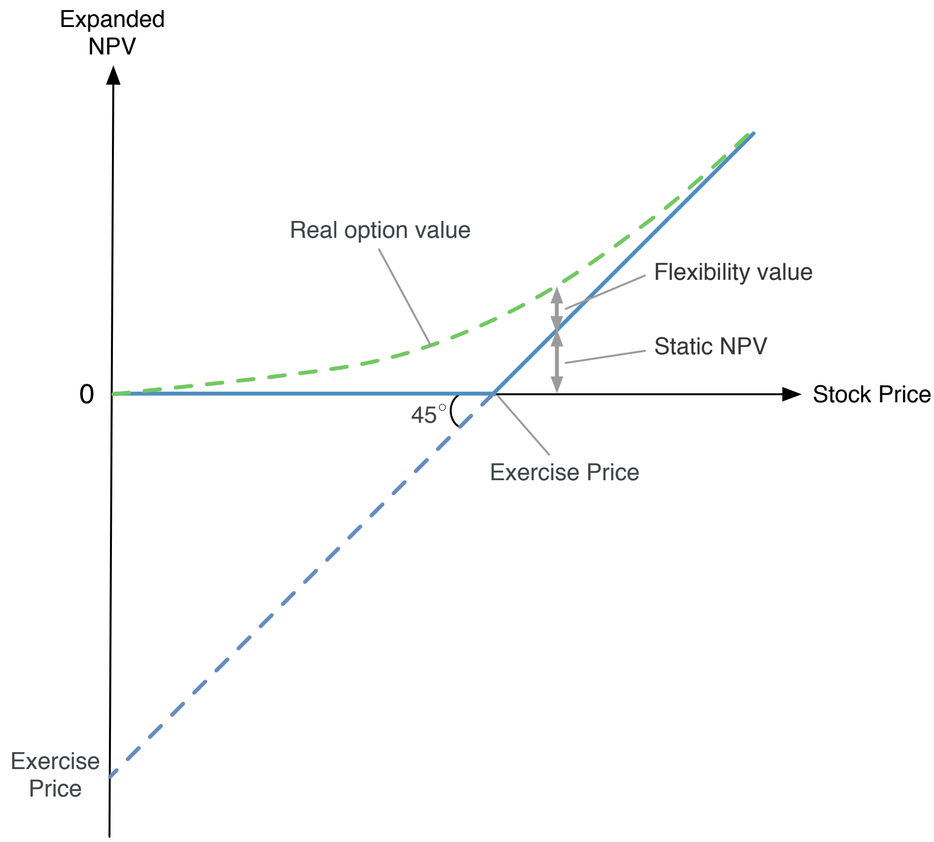


Figure 36: Analogy of a call option with the flexibility to wait (adapted from [276]).

The eNPV, also called the total strategic value, therefore represents the sum of the deterministic base case net present value and the strategic options value [232]. The value of flexibility is calculated as the value of the real option. Various methods and modeling approaches exist to assess the value of an option, depending on the nature and structure of the problem: Payoff function, Binomial and Lattice Approach, Closed-Form equations (Black & Scholes), Partial Differential Equations (Finite Difference Methods) and Dynamic Stochastic Programming, Simulation, etc. Additional information with respect to these approaches can be found in [232], [226], [157] or [51].

Finally, of particular interest to this research, is the ability of Real Options to analyze and value multistage and interdependent project investments. This type of options where project interdependencies are considered for project valuation, is called *nested* options.

Nested options often provide a better understanding of the dependencies and sequencing constraints associated with some projects [22]. Additionally, nested options enable a more accurate valuation of the projects. In the context of this research, by investing in a particular set of technologies, airport managers create subsequent, downstream, investment opportunities, therefore increasing the strategic impact that such investments may have on the airport. Notional examples of potential investment sequences are represented in Figure 37.

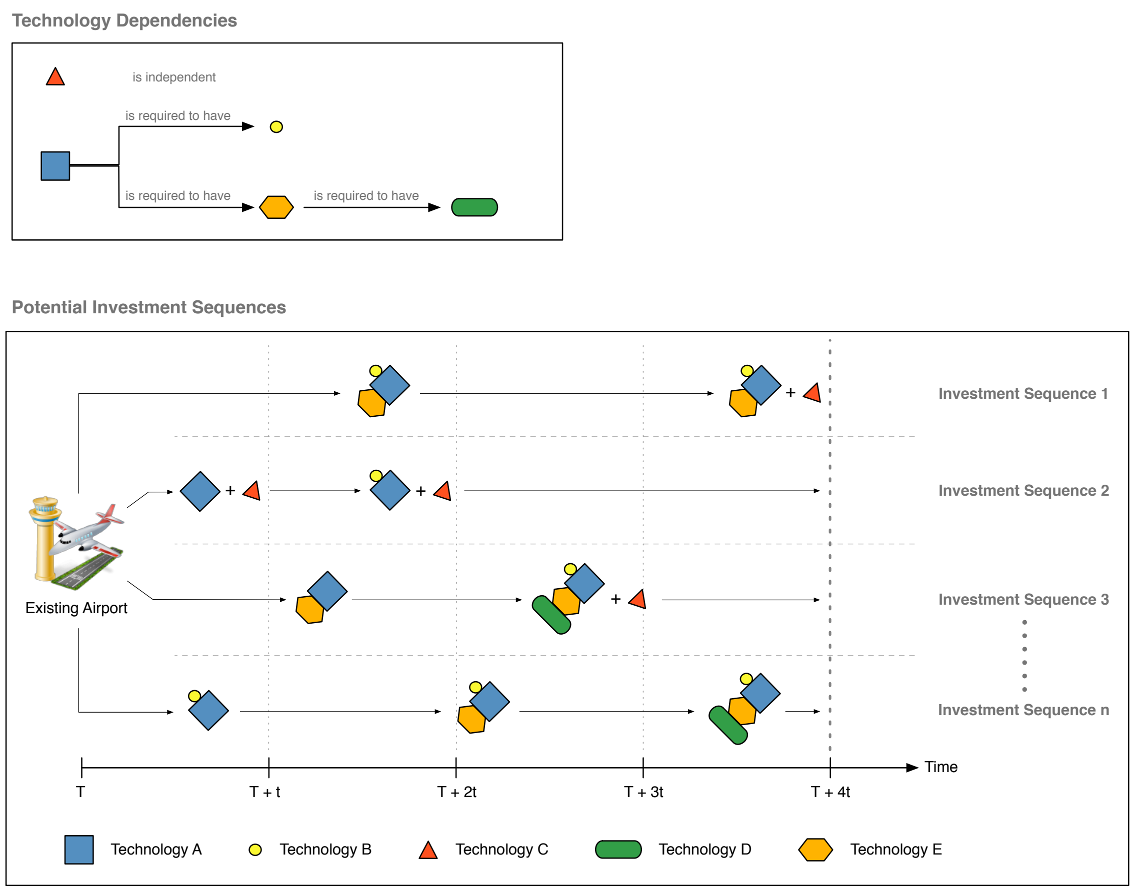


Figure 37: Notional examples of potential technology dependencies and investment sequences.

To conclude, real option analysis provides managers and decision-makers with a flexible path forward, allowing them to adapt their investment decisions as some uncertainty get resolved and new information becomes available [232]. Hence, one of the main advantages of real options analysis is that the value created by managerial flexibility and the ability to respond to future uncertainties is integrated into the valuation process [39]. In particular, the value of flexibility is captured by an expanded NPV (eNPV) criterion, which allows for the valuation of flexible projects [276]. Finally, real option analysis presents an essential framework to evaluate sequential investment decisions. However, as with any method, it is important to point out some drawbacks and limitations.

Drawbacks and Limitations of Real Options Analysis:
While the theory behind real options is "sound and reasonability applicable" [232], it is one of the most complex valuation methods [212, 82]. In particular, determining the exercise price and volatility of a real asset is a challenging undertaking as the costs and resources necessary for the accomplishment of the project may not be known exactly [39]. Additionally, the risk-free interest rate is difficult to obtain, as there is no arbitrage-free markets where underlying assets are traded [58]. Also, in some instances, it may be difficult to identify the potential options, their sequence, and their interactions; chose the right variables as inputs, and estimate their boundaries or distributions; and solve the appropriate mathematical models [157].

2.9.3 Observation

As discussed, many value-centric methods exist to appraise capital investment projects. However, from this review, it is apparent that the most traditional approaches (DCF, standard NPV, and DA) may underestimate the true economic value of investments [267] because they fail to capture the value created by managerial flexibility and the growth opportunities provided by new investments [304]. Hence, the context of this problem, characterized by uncertainty and the need to integrate flexibility in the investment decision process, makes the implementation of these conventional techniques inappropriate. As extensively addressed, real option analysis, on the other hand, provides the framework necessary to integrate, capture and value the flexibility embedded in projects in general, and sequential project investments, in particular. In light of this discussion, the following hypothesis to Research Question 3.2. is proposed:

Hypothesis 3.2: The strategic value of the flexibility embedded in technology portfolios can be captured through the formulation of sequential nested options and represented as the value of the real option.

Real options analysis has been applied to air transportation problems in the past. The following section reviews and discusses some of the most relevant work.

2.9.3.1 Real Option Analysis in Air Transportation

Miller and Clarke (2003) [222] developed a methodology to support investment decisions in air transportation infrastructure using real options to evaluate the strategic value of infrastructure. Their proposed method is applied to a single-runway airport that considers building a second runway after the first phase of an infrastructure expansion project has been completed. The question they are trying to address is thus the following: is the value of the real option (building a second runway) greater than the cost of the real option (buying the land)? To address it the authors define the real option as the building of a second runway, the underlying asset as the expected revenues generated from the travel demand served by the second runway, the exercise price as the cost associated with building and maintaining the runway, and the cost of the real option as the price of the land where the second runway is to be built. They also modeled the option as a European call option arguing that capital expansion projects have fixed deadlines at which investment decisions should be made. In particular, their research recognizes the coupling between internal market dynamics projects to external dynamics, and therefore implements system dynamics to model the underlying asset (S) and strike price (X). Their proposed approach is depicted in Figure 38.

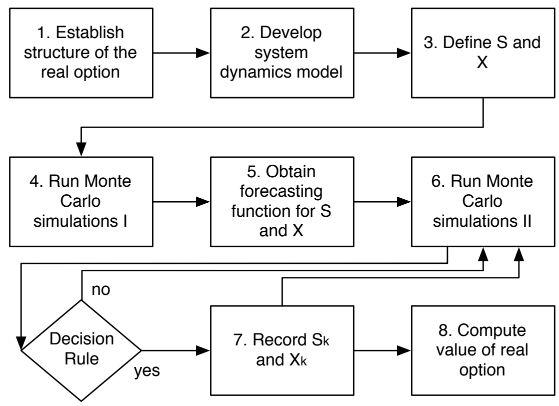


Figure 38: Main steps of the methodology proposed by Miller and Clarke [222] to determine the strategic value of air transportation infrastructure.

The computation of S and X is then coupled with Monte Carlo simulations to determine a forecasting function for the decision rule based on a regression of the payoff calculated at each run *k*. The value of the real option is then obtained by incorporating this forecasting function and the decision-rule into the system dynamics model and running another set of Monte Carlo simulations. One of the particularities of Miller's and Clarke's work is that it considers the cost to exercise the option to be probabilistic in nature as opposed to be fixed. Additionally, the discount rate used is not fixed either and varies depending on the financial performance of the project over time. Their work, by incorporating a system dynamics model and a decision rule to a real options framework, successfully captures the changes in the environment faced by decision-makers. It also provides information regarding the effect of a decision on the system. The major drawback to this approach, as noted by the authors, is the impossibility to find an optimal decision path. On a more philosophical level, this study illustrates the power of real options to address infrastructure expansion problems. In particular, this work shows the value of paying a small initial investment to be able to rapidly capture growth opportunities, as opposed to making a final decision to expand at the very beginning of a project.

In a related study, Miller and Clarke (2005) [224] propose an evaluation methodology based on system dynamics and Monte Carlo simulation in a real options framework to evaluate different flexible infrastructure deliveries. Using the same system dynamic model and approach as the one previously described, the authors assume that the value of flexibility can be computed as "the difference between the value of the flexible strategy and the maximum of the value of the inflexible strategies or zero" [224]. The value of inflexible strategies, in particular, is obtained by computing the mean of the net present values for each Monte Carlo run. The value of the flexible strategy, on the other hand, is obtained by taking the expected value of the value of the option, w, where w is the difference between the expected value of revenues given that the option is exercised and the costs associated with exercising that option.

2.9.3.2 Remarks

Most of the work related to the use of ROA to address airport expansion projects has so far not considered sequential investment options. Hence most of the studies use real options to evaluate "go or no-go" decisions based on a single project. The need to address interdependencies between projects has been acknowledged by many [2, 22, 25]. However project interdependencies have very rarely been implemented from a real option perspective at the airport level.

2.10 Final Remarks

The problem and challenges that this work is attempting to address have been discussed through a thorough review of the state-of-the-art and the concepts, methods and studies associated with it. This led to the formulation of several research questions and hypotheses. A synthesized view of the mapping between the assertions made in Chapter 1 and the Research Questions and Hypotheses formulated in this chapter can be found in Figure 39.

These research questions, to be answered, therefore call for the formulation of an approach that addresses some of the needs, pitfalls or limitations identified throughout this chapter. Such an approach is provided in the following chapter.

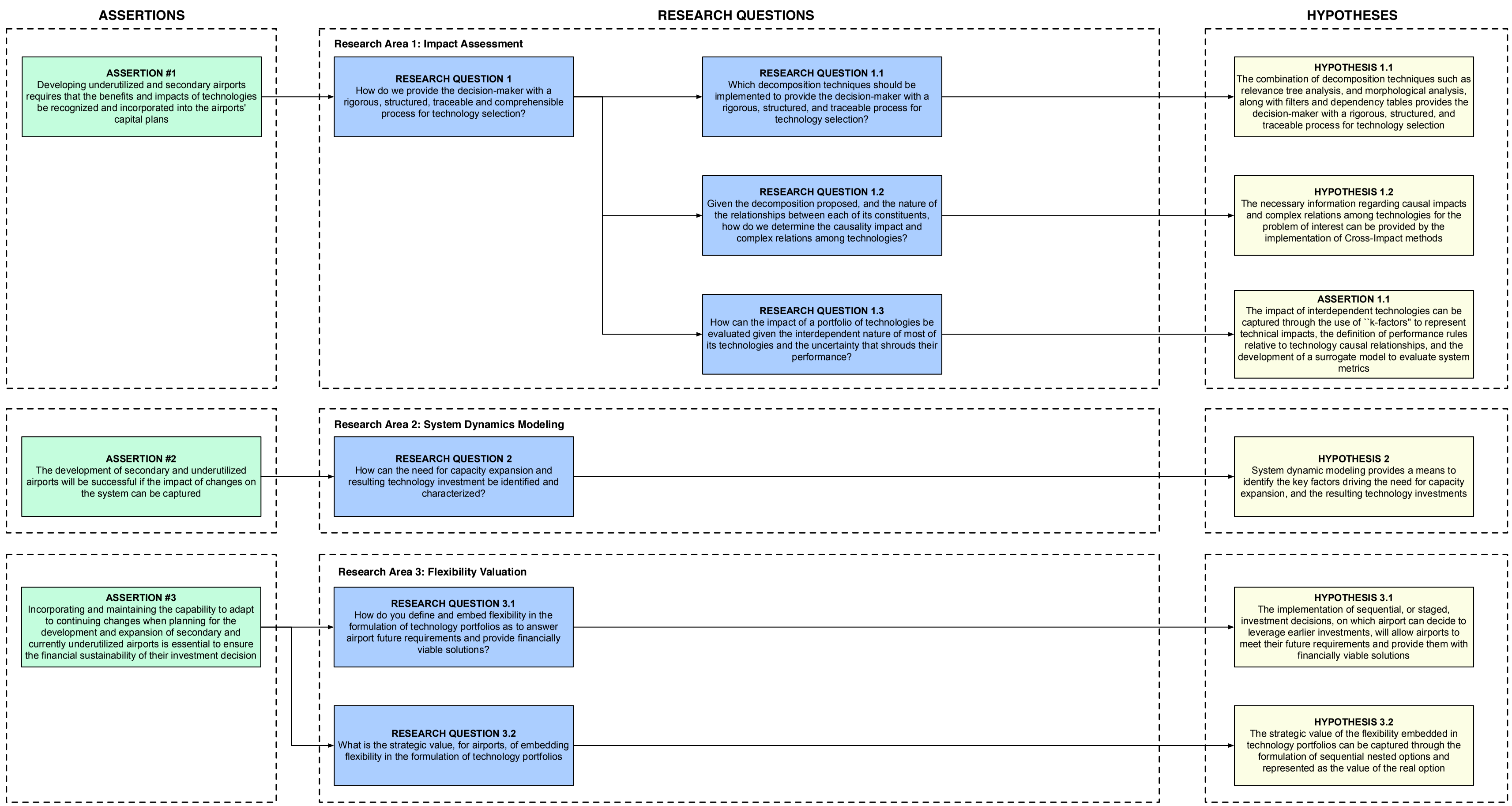


Figure 39: Final structure of the assertions, research questions and hypotheses of this research.

CHAPTER III

PROPOSED APPROACH

This research focuses on the implementation of operational concepts and technologies at small and medium airports as a means to address the expected increase in demand and resulting capacity issues. However, as discussed throughout Chapters 1 and 2, there exists many challenges associated with sustaining the development of this type of airports. In particular, the need to synchronize evolving technologies with airports' needs and investment capabilities was recognized as being an important one. Additionally, it was observed that the evolution of secondary airports, and their needs, are tightly linked to the environment in which they operate. In particular, sensitivity of airports to changes in the dynamics of their environment was emphasized, and the necessity to identify the factors that drive the need for technology acquisition was acknowledged. Finally, the difficulty to evaluate risk and make financially viable decisions, particularly when investing in new technologies, was recognized. More importantly, the potential benefits of providing the capability to adapt to evolving circumstances as a way to mitigate risk and address uncertainty were discussed. The assertions made in Chapter 1, along with the careful review of the state-of-the-art, challenges and shortcomings associated with each of them 2, lead to the formulation of the main goal and objectives of this research:

Research Goal:

To provide airport decision-makers with the capability to valuate and select adaptable technology portfolios to ensure airport financial viability.

Research Objectives:

1. To provide airport decision makers with a rigorous, structured, and traceable process for technology selection

2. To identify and characterize the need for capacity expansion and resulting technology investments

3. To provide airport decision makers with the capability to adapt to fluctuations in the air transportation industry

The methodology proposed in this chapter is further described in detail in Chapters 4 through 7. It is formulated such as to support the aforementioned research goals and objectives and addres the hypotheses and research questions formulated in Chapter 2. Hence, this methodology, whose structure is illustrated in Figure 40, is articulated around the following steps:

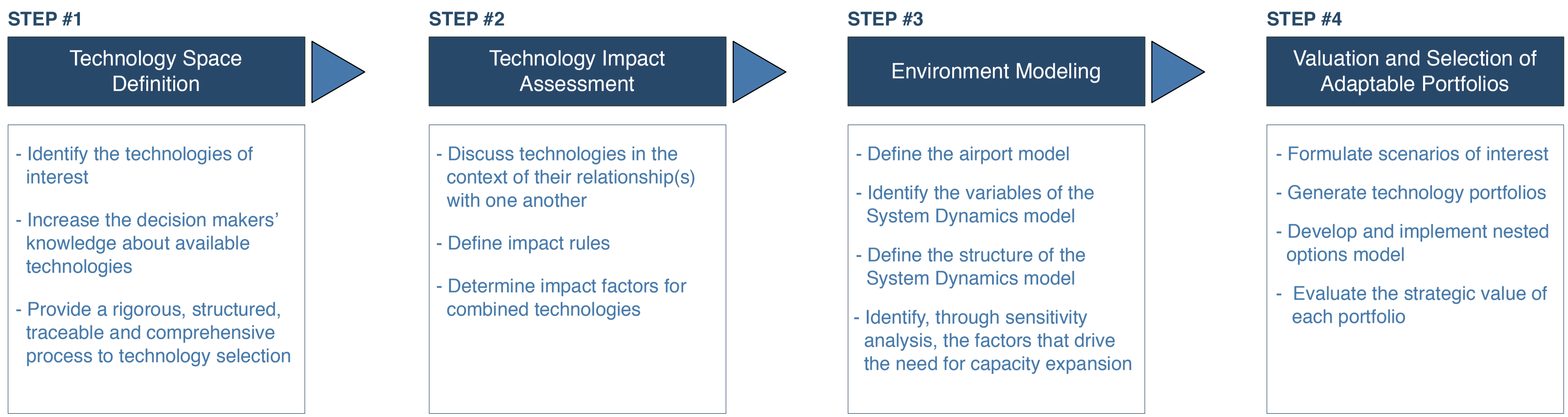


Figure 40: Proposed approach.

3.1 Step #1: Technology Space Definition

The objective of this first step is to identify the technologies of interest for this research and increase the decision makers' knowledge about them. In other words this step is in place to provide a better picture of the options available to the decision makers. As mentioned previously, many technologies exist that have the potential to satisfy airport operational needs. However, these technologies are interrelated, bring different benefits to airports, and are available at different points in time. This first step provides a step-by-step description and implementation of the tools, methods and techniques that support the identification and selection of technologies of interest. In particular, it discusses how relevance tree analysis and morphological analysis, along with filters and dependency tables are implemented to provide a rigorous, structured, traceable and comprehensive process to technology selection. This step is described in Chapter 4.

3.2 Step #2: Technology Impact Assessment

The objective of this step is first to identify technology relationships, and second to provide a framework to assess the impact of combined technologies. This step, further described in Chapter 5, first discusses technologies in the context of their relationship(s) with one another. It then builds on identified technology relationships to define impact rules (Section 5.1). These impact rules then provide the basis for the determination of combined technologies impact factors for any given metric (Section 5.2).

3.3 Step #3: Creation of the Modeling and Simulation Environment

The objective of this step, addressed in Chapter 6, is to help identify the need for capacity expansion and the factors that drive this need. Hence, this step first discusses the two main components of this environment: an airport model (Section 6.1), that supports the translation of technology impact factors into airport performance indicators, and a System Dynamics model (Section 6.2) that helps identify the key factors, among the ones included in the M&S environment, that drive the need for capacity expansion. It also presents the overall architecture and logic behind this environment (Section 6.3). Finally, this step concludes by discussing the use of Systems Dynamics and sensitivity analysis as a means to fulfill the aforementioned objective.

3.4 Step #4: Valuation and Selection of Adaptable Portfolios

The objective of this step is to identify technology portfolios with high strategic values, i.e. technology portfolios that support a wide range of futures. This step first describes the scenarios of interest and further discusses the formulation of technology portfolios within the framework developed in Chapter 6. It then details the development and implementation of a real option framework to evaluate the strategic value of portfolios.

As mentioned in Chapter 2 Section 2.1, the air transportation industry has reached a peak with existing technologies having achieved maturity. New technologies are thus being developed, mainly through the NextGen and SESAR programs, to help the industry meets its future needs. However, selecting technologies of interest is a challenging undertaking due to the interdependent, interrelated and time-dependent nature of their relationships. The following chapter describes the development of a rigorous, structured, traceable, and comprehensible process for technology selection.

CHAPTER IV

STEP #1: TECHNOLOGY SPACE DEFINITION

This chapter discussed the creation of a rigorous, structured, traceable and comprehensible process for technology selection. In particular, it provides a step-by-step description and implementation of the methods and techniques proposed to create such process. As discussed in Chapter 2 Section 2.1, the first step should consist in decomposing the problem.

4.1 Step 1a: Problem Decomposition

Functional decomposition by traffic management phases was identified as a means to achieve this goal (Section 2.2). In particular, functional decomposition techniques such as relevance tree analysis and morphological analysis, along with filters and dependency tables were expected to provide the decision-maker with a rigorous, structured, and traceable process for technology selection (Hypothesis 1.1). This work thus proposes to implement the aforementioned decomposition techniques as illustrated in Figure 41.

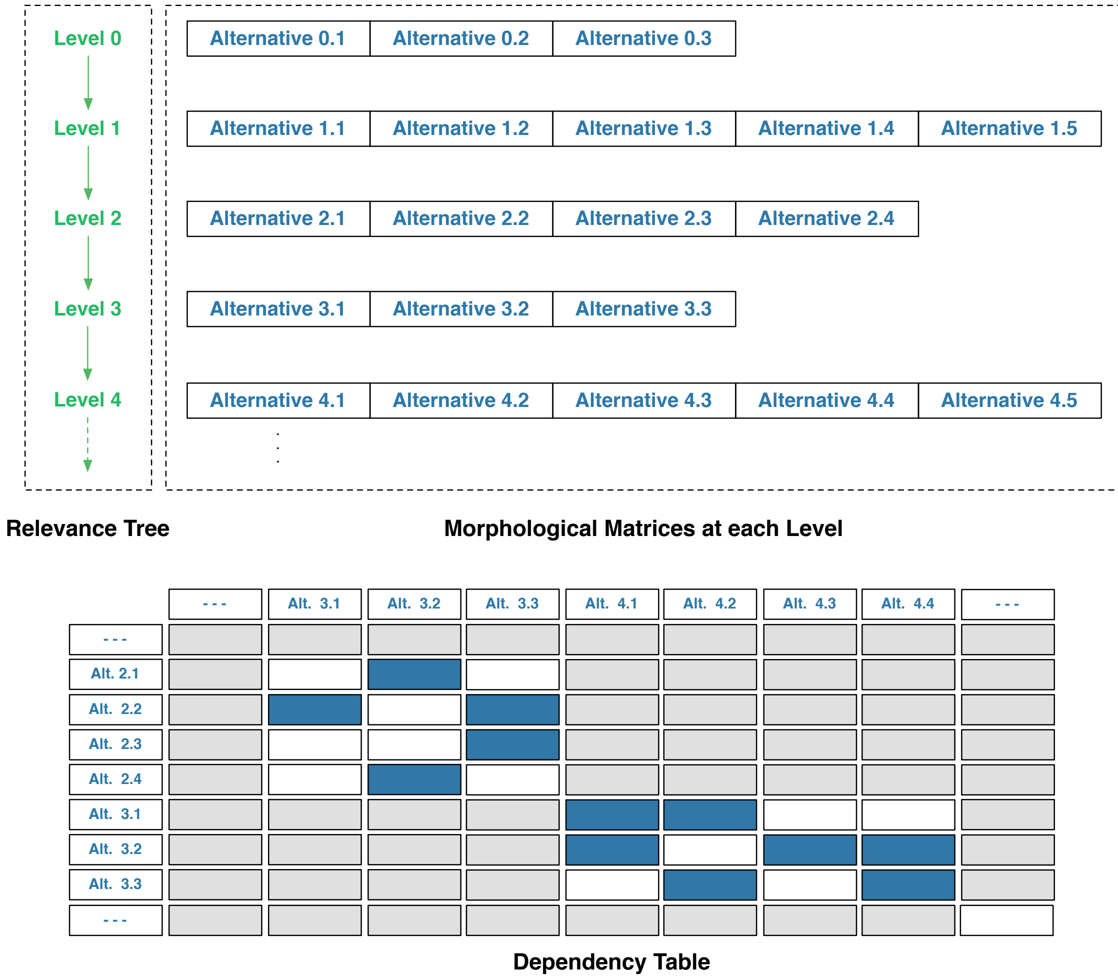


Figure 41: Proposed Use of decomposition techniques.

While the decomposition by traffic management phases (Level 0 of the relevance tree) offers many advantages, it does not fully address the multi-dimensionality of the problem. Further decomposition of the problem is therefore necessary. A multi-level decomposition [252], inspired from the study and structure of the NextGen and SESAR architectures is represented in Figure 42.

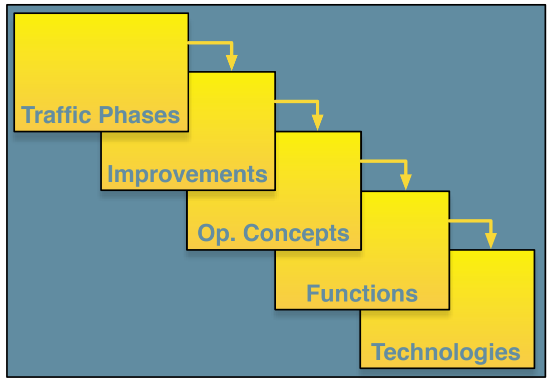


Figure 42: Decomposition layer.

The different levels 0, 1, 2, 3, 4 and 5 of the relevance tree thus correspond to traffic phases, improvements, operational concepts, functions, and technologies, respectively. Matrices of alternatives are then created for each level. The first matrix (Level 0) is based on the decomposition by traffic management phases described above with potential improvements being provided as options for each of the different phases. Operational concepts are then mapped to the different possible improvements and further defined in terms of the functions they fulfill. Finally, on-ground technologies enabling these functions are provided for the decision-maker to choose. Additional information with respect to necessary on-board or sub-technologies can also be included. An example of this process is illustrated in Figure 43.

It is important to note, however, that the combinatorial space described by both the number of matrices and the variety of options possible for each of them is too large to enable technology down-selection. Filters, as well as compatibility and dependency relationships, therefore need to be defined and implemented to reduce the number of possible alternatives and streamline the selection process. Additionally, filling these matrices of alternatives requires that options for each of the layers be identified. This aspect is discussed in the following section.

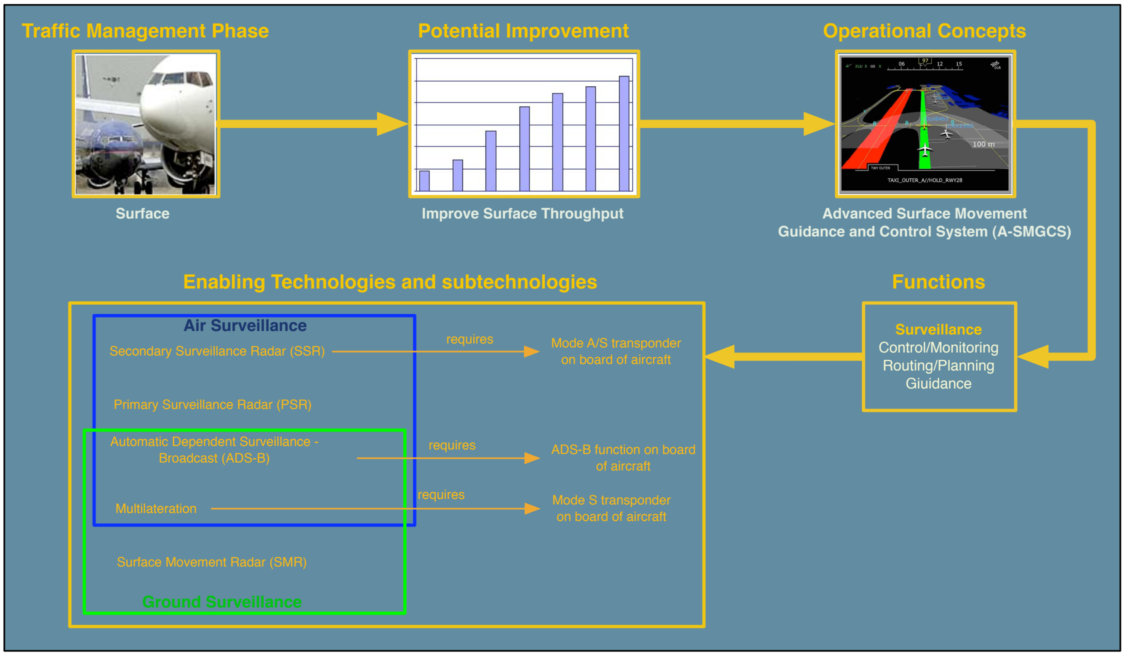


Figure 43: Example of decomposition.

4.2 Step 1b: Technology Identification

As previously discussed, industry growth cannot be sustained indefinitely with current technologies. Both the United States and the European Union have been working to address the challenge of satisfying the expected doubling in demand in a safe, secure and environmentally friendly way. In the United States, President Bush signed in December 2003 the "Vision 100" legislation (Public Law #108-176) that established the Joint Planning Development Office (JPDO) to develop "the design and deployment of a modernized aviation system called the Next Generation Air Transportation System (NextGen)" [121]. The national needs and goals for NextGen have been described in the "Next Generation Air Transportation System (NGATS, now called NextGen) Integrated Plan" [177] released in 2004. In 2005, JPDO presented a high-level vision for the key operating principles and characteristics of NextGen in the *NGATS Vision Briefing*. More recently, in 2010, the JPDO refined a Concept of Operations (ConOps v3.2) for the Next Generation Air Transportation System [181] and added the *Enterprise Architecture Version FY13* to the NextGen Joint

Planning Environment (JPE) [182]. It also released the *Integrated Work Plan (IWP) Version FY13* [182], and the Executive Summary for the *Integrated Work Plan (IWP) Version FY13* [175] which provide information about operational improvements, enablers, policy issues, development activities, and research activities. These documents also detail the different milestones, and responsibilities to support collaboration among partners and stakeholders. Similarly, the European Union has been working on The Single European Sky ATM Research (SESAR). SESAR is the technological and operational component of the Single European Sky (SES) that should provide all the European ATM stakeholders with "a road map for the implementation of the system until 2020" [112]. More particularly in 2008, EUROCONTROL, which led the Definition Phase of SESAR, released the *European ATM Master Plan (e−ATM Master Plan)* [105, 107] and the associated *Work Programme for 2008-2013* [106]. This Master Plan, endorsed by the Council of the European Union in 2009 [64], has been updated and refined in 2010 [17]. It defines the content, and establishes the roadmap for the development and deployment of the next generation of ATM systems up to 2020 and beyond. Other strategies and plans, such as the *ATM 2000+ Strategy*, the European Air Traffic Management Program (EATMP) or the *Strategic Guidance in Support of the Execution of the European ATM Master Plan* [108] have been produced over the last 11 years to define and support the development and implementation of the different ATM operational improvements necessary to the realization of a safe, secure and seamless airspace [94, 97, 96]. The new technologies and operational concepts they describe are being developed and tested to help meet the industry's future needs from both sides of the Atlantic. Given the context of this research, it is primordial to focus on technologies and operational concepts that help airports leverage their infrastructures' potential capacity under all conditions.

In this respect, among the multitude of operational improvements described in both the *Integrated Work Plan for the Next Generation Air Transportation System - Version FY13* and dataset Version 002.30 available on the *European ATM Master Plan (e−ATM*

Master Plan) Portal [110], only the ones which may offer potential benefits to the following traffic management phases are considered: Approach/Departure transition, Final Approach/Initial Departure, and Surface levels.

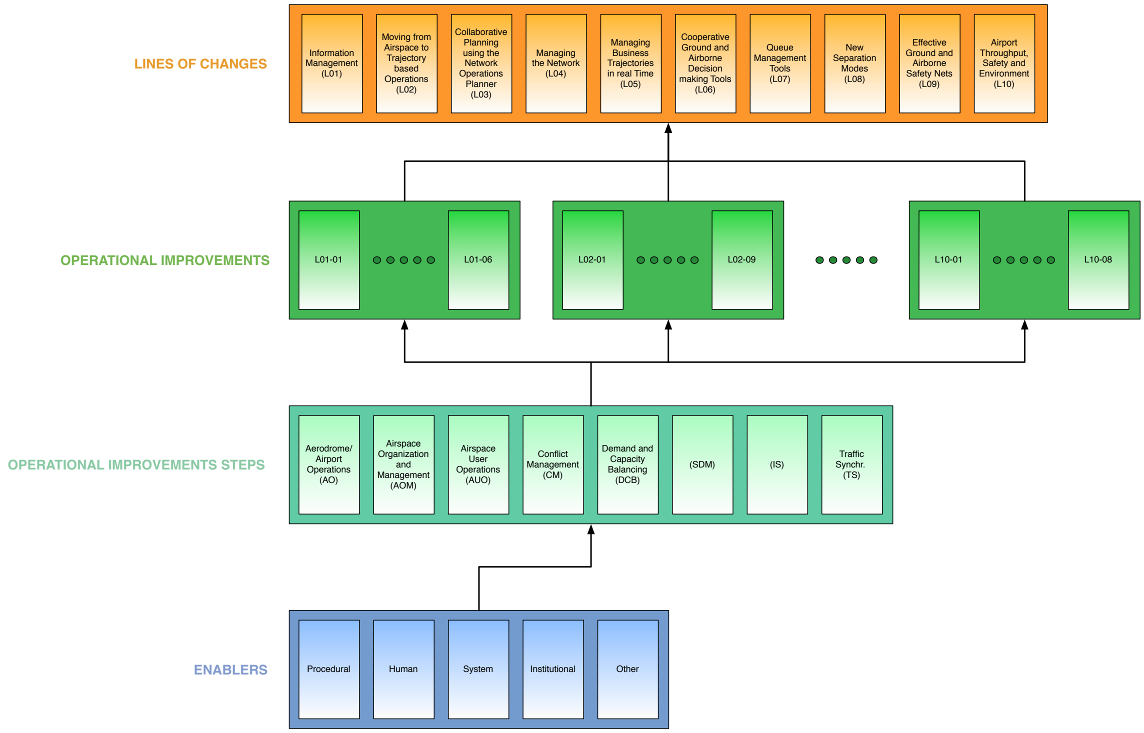
Populating the different matrices of alternatives thus requires a thorough study of the different improvements, operational concepts, and technologies, existing or under development under both NextGen and SESAR programs, associated with these traffic management phases. Also, to ensure that the technologies or concepts selected by the decision-maker are program-independent (see discussion in Section 2.2), it is paramount that similar operational concepts or technologies be identified across both programs. The steps leading to the identification of similarities between NextGen and SESAR are fully detailed in [253], and briefly described in the following paragraphs.

4.2.1 Identification of Similar Operational Improvements

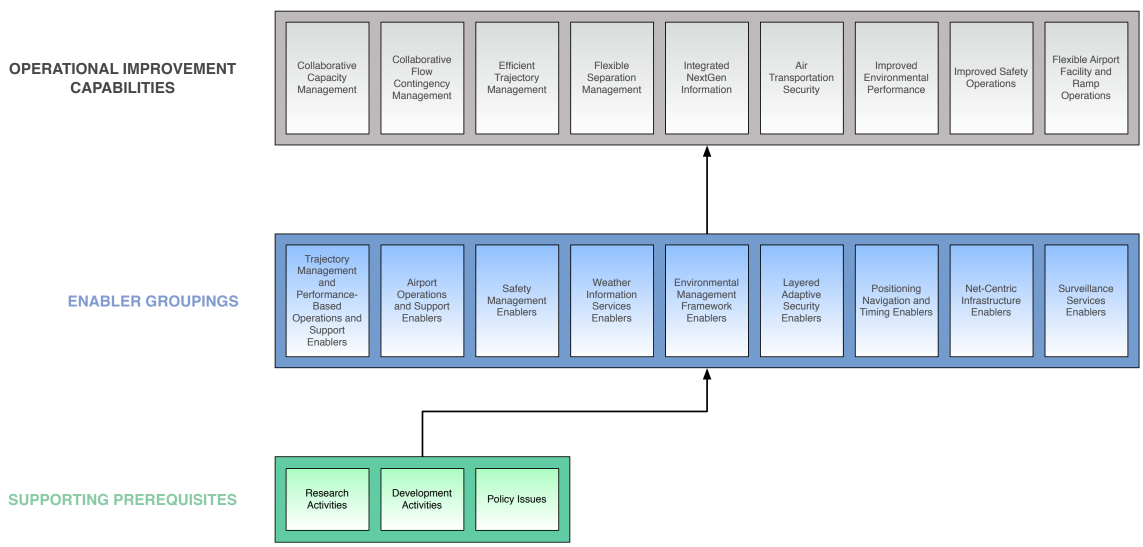
As illustrated in Figure 44, NextGen and SESAR offer similar yet slightly different structures. To alleviate these differences, Operational Improvement Steps and Operational Improvements, as defined under SESAR, are lumped together. Hence, for example, the Operation Improvement Step *AOM-0701: Continuous Descent Approach*, associated to the Operational Improvement *L02-08: Optimizing Climb/Descent* in SESAR, becomes the operational improvement *L02-08-AOM-0701: Continuous Descent Approach*. Operational concepts are selected based on the potential benefits they may provide at the Approach/Departure transition, Final Approach/Initial Departure, and Surface levels. This selection originally includes 53 NextGen operational improvements and 88 newly defined SESAR operational improvements. Comparisons of the different operational improvements are then made based on their descriptions, obtained primarily from the *NextGen Integrated Work Plan - Version FY13* and *European ATM Master Plan (e−ATM Master Plan) Portal*. Each description provides information with respect to the goal and focus of the concept, its timescale, as well as its enabling systems, procedures, technologies, and potential benefits. However, due to the high number of descriptions considered and concepts discussed within these descriptions, it is increasingly difficult to form a clear understanding of the underlying relationships and similarities between NextGen and SESAR operational improvements by comparing them manually. A more analytically efficient way of reviewing the information is thus necessary. This alternative approach, described in the following section, is provided by the field of Visual Analytics.

4.2.1.1 The Use of Visual Analytics

Visual Analytics originates from the effort of the U.S. Department of Homeland Security (DHS) to develop new methods to facilitate situational assessment and decision-making, with the objectives of preventing emerging threats, countering future terrorist attacks, protecting American borders, and quickly responding in an event of an attack or disaster [300]. Visual Analytics is a highly interdisciplinary field of research [189] defined by Thomas and Cook as "the science of analytical reasoning facilitated by interactive visual interfaces" [300]. Visual Analytics leverages and integrates techniques related to analytical reasoning, visual representation and interaction, and data representation and transformation, to provide analysts with the capability of synthesizing information thereby gaining new and often unexpected insights from massive and ambiguous sets of data.



(a) e−ATM master plan components



(b) NextGen integrated work plan

Figure 44: More detailed representations of both structures.

In this research, a visual analytic system called `Jigsaw` [281], developed between 2006 and 2007 at the Information Interfaces Lab at the Georgia Institute of Technology, was used to more efficiently examine and relate the information associated with each operational improvement. `Jigsaw` provides "visual representations of the information within textual documents and report collections in order to help analysts search, review, and understand the documents better" [280]. In particular, this system highlights connections and relationships between entities in the documents through a series of interactive visualizations [280]. Entities can be of any type. In the context of this work, entities describing the traffic phases, Initial Operational Capability (IOC) indicators, focuses, benefits, as well as the procedures, concepts and systems relevant to each operational improvement were identified for each description. Entity aliases were created when two documents had similar but differently worded entities (*adverse conditions* vs *bad weather*, for example).

Additionally a "Title" entity was created for each document, with documents consisting of descriptions of OIs as provided by their respective associated work plans. The description and entities associated with the NextGen Operational Improvement OI-0320 (*Initial Surface Traffic Management*) are provided in Table 15 as an example.

The suite of interactive and distinct visualizations offered by `Jigsaw` consists of a series of views: a List View, a Graph View, a Scatter Plot View, a Document View, a Calendar View, a Document Cluster View, a Timeline View and a WordTree View. More information about each of these views can be found in Stasko et. al [281]. The perspective offered by the List View and Graph View, which both present entities as well as documents as units of interactions [280], are illustrated as an example in Fig. 46. Also, `Jigsaw` does not show the entire dataset at once. Instead, it proposes a query-based approach which only shows the dataset relevant to the information being queried [280]. A discussion on how `Jigsaw` was implemented on a dataset describing operational improvements from both programs is provided in the following Section.

Table 15: Description and entities associated with NextGen OI-0320

Description	Departures are sequenced and staged to maintain throughput. The Air Navigation Service Provider (ANSP) uses automation to inte--grate surface movement operations with departure sequencing to ensure departing aircraft meet departure schedule times while optimizing the physical queue in the movement area. ANSP auto--mation also provides surface sequencing and staging lists for departures and average departure delay (current and predicted). These functions will incorporate traffic management initiatives, separation requirements, weather data, and user preferences, as appropriate. ANSP automated decision support tools integrate surveillance data, weather data,departure queues, aircraft flight plan information, runway configuration, expected departure times, and gate assignments. Local collaboration between ANSP and airport stakeholders improves information flow to decision support as well as the ability for aircraft operators to meet their operational and business objectives
Title	Initial Surface Traffic Management
IOC Indicators	2014
Focuses	Surface movement Surface sequencing Departure sequencing High-density airports
Phases	Surface Departure
Procedures, Concepts and Systems	Departure-scheduling tools Decision support tools Surveillance data Automation
Benefits	Improved information flow to decision support Ability for aircraft operators to meet their operational and business objectives Reduced delays and environmental impacts More efficient operations

4.2.1.2 Identification of Connections and Relationships between Operational Improvements

Each NextGen operational improvement is queried through `Jigsaw`. The document associated with the OI being queried appears as a node in the Graph View, as illustrated in Fig. 45. This node can then be further expanded to reveal the different entities relevant to the document of interest. If a similar entity is found in a document describing a different OI, a connection will be created between these two documents. After filtering out all but the "Focus" entities, and expanding all nodes, all connections between relevant documents are represented. An example of a Graph View representation resulting from querying the NextGen Operational Improvement OI-0320 is provided in Fig. 46(a). Similar connections can be obtained using the List View, as illustrated in Fig. 46(b). The first, second, and third lists were set to display information corresponding to the document's title, focus, and ID number, respectively. Selecting the title corresponding to the NextGen Operational Improvement OI-0320 (*Initial Surface Traffic Management*), the system then provides a list of focuses associated with that document. Further selecting the different focuses of that particular OI leads to the ID number of all additional relevant documents. The color mappings represent the strength of the connection, with darker orange representing the strongest connections. All NextGen OIs can thus be mapped to focus-related SESAR OIs following this process. Tables summarizing the mappings between NextGen and SESAR OIs can be found in Appendix A. It is important to note when studying these tables that, because many Operational Improvements describe ideas that are either analogous or related, comparisons between NextGen and SESAR OIs rarely result in a one to one mapping.

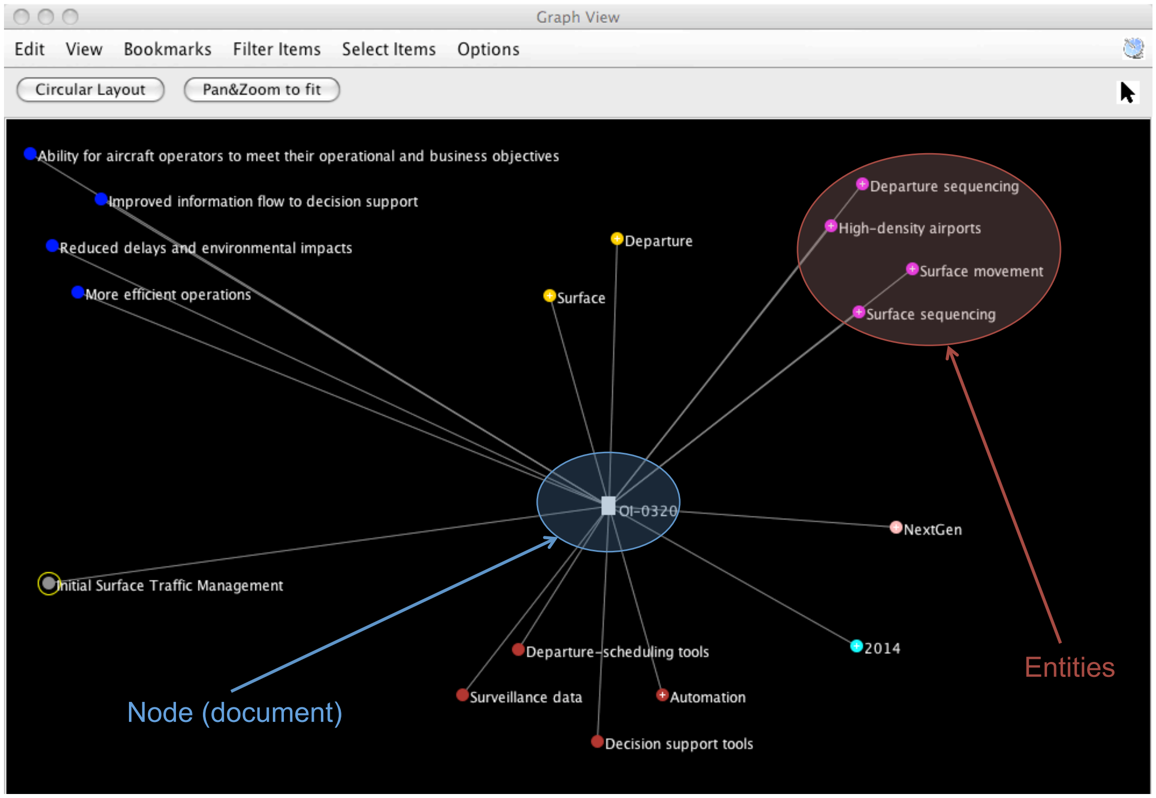
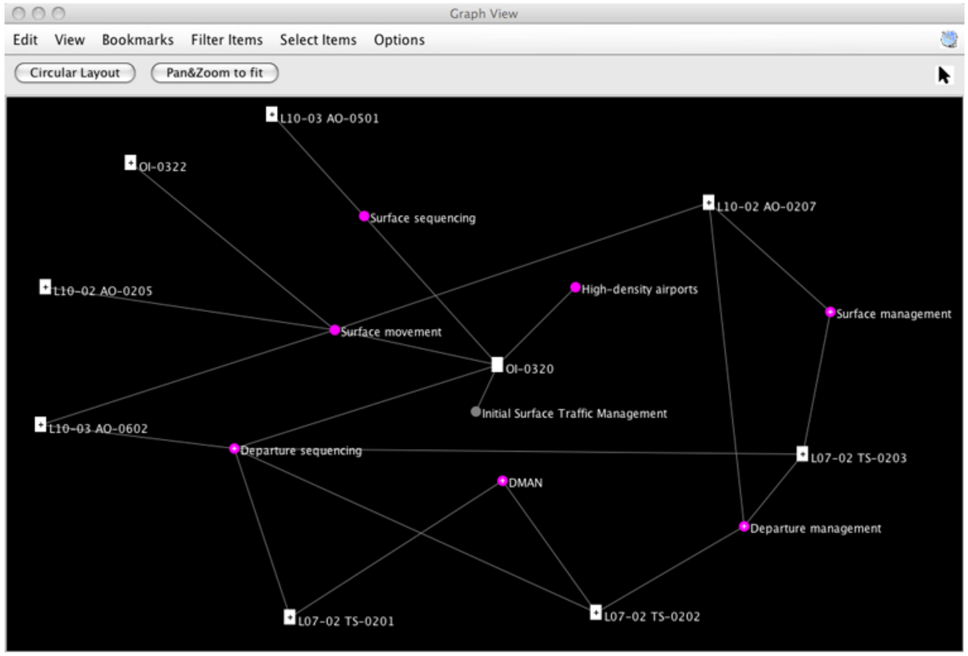
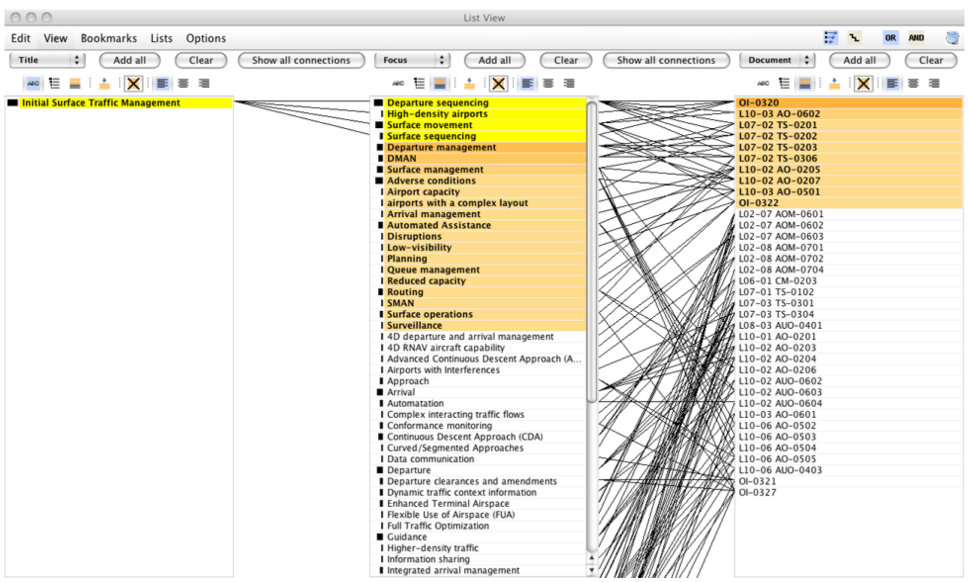


Figure 45: A node and its relevant entities in a graph view.

While identifying commonalities between NextGen and SESAR at the Operational Improvement level is important, it provides limited information as to potential similarities at lower levels (enablers, etc.). The next step, as described in the following Section, built on this first effort to identify similarities in terms of technologies for related OIs.



(a) Graph view.



(b) List view.

Figure 46: Views of the relationships between OI-0320 and a subset of newly-defined SESAR operational improvements.

4.2.2 Identification of Related Technologies

Each of the aforementioned OIs' enablers are identified from work plans and related documentation. The decomposition proposed in Figure 42 is then applied to these different OIs. Improvements and functions supported by each OI are identified through a careful review of the literature. An example of such a decomposition applied to SESAR Operational Improvement L10-02 AUO-0602 *(Guidance Assistance to Aircraft on the Airport Surface)* is proposed in Figure 47. Improvement categories are then created when OIs support similar improvements.

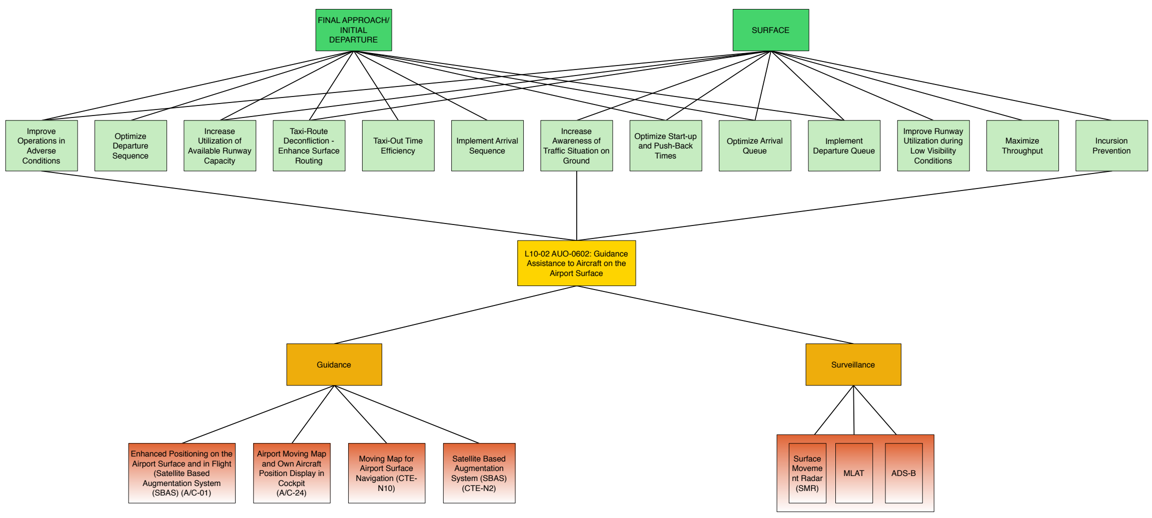


Figure 47: Applied decomposition to SESAR OI L10-02 AUO-0602 *(Guidance Assistance to Aircraft on the Airport Surface).*

As discussed in the literature, enablers encompass both material and non material components. The NextGen Integrated Work Plan describes enablers as communication, navigation, and surveillance systems, as well as procedures, algorithms, and standards. Similarly, SESAR enablers are divided into human, institutional, procedural and system enablers. For simplification purposes, this work only considers ground system enablers, in other words, enablers supporting communication, navigation, and surveillance systems, ground management systems, etc.

Also, in some instances, descriptions of enablers lack details, making it difficult to associate such enablers with technologies. An example is the SESAR enabler titled *AERODROME-ATC-02: Surface Movement Management Tools Updated for Enhanced Conflict Detection and Alert*. Such enablers are thus disregarded. Similarly, when an operational improvement is described only in terms of these enablers, the operational improvement itself is excluded. Additionally, it may happen that the enablers listed do not directly translate into one specific technology, but rather into a type, or family, of technology. For example, *OI-0340: Near-Zero Visibility Surface Operations* requires non-cooperative surveillance. This function can be fulfilled by technologies such as the Legacy Long Range Radar (LRR), the Legacy Airport Surveillance Radar-8 (ASR-8), or the Legacy Airport Surveillance Radar-9 (ASR-9), etc, all of which are primary surveillance radars. Such technologies are thus lumped together to avoid having to enumerate and differentiate between them.

The resulting groupings discussed below are created based on the information available to the author, and are believed to provide the necessary granularity for the scope of this work.

4.2.2.1 Grouping of Surveillance Technologies

Surveillance technologies are classified into non-cooperative independent surveillance (primary surveillance radars), cooperative independent surveillance (secondary surveillance radars, multilateration, etc.), and cooperative dependent surveillance (automatic dependent surveillance broadcast (ADS-B) in/out, etc.). Non-cooperative surveillance entails that the aircraft/vehicle can be detected without relying on any particular equipment installed onboard (no action is required from the target aircraft/vehicle). Cooperative surveillance, on the other hand, requires that an operating transmitting/receiving device (e.g. a transponder) be present onboard. In the case of independent surveillance, the position of the aircraft is computed on the ground, while with dependent surveillance the position of the aircraft/vehicle is provided by the aircraft/vehicle itself. For the purpose of this work, all primary surveillance radars (Legacy LRR, Legacy ASR-8, etc.) mentioned in the literature were lumped into a technology titled “Primary Surveillance Radar (PSR)”. For Secondary Surveillance Radar (PSR), a distinction was made between “Legacy Secondary Surveillance Radar” and “Next Generation Surveillance Radar”, an example of which would be the Air Traffic Control Beacon Interrogator Model 6 (ATCBI-6). Other surveillance technologies considered in this research include the Airport Surface Detection Equipment (ASDE-3/X), the Automatic Dependent Surveillance -Broadcast (ADS-B) out, the Surface Movement Radar (SMR), the Multilateration (MLAT), the Wide Area Multilateration (WAM) and the Precision Runway Monitor (PRM) system.

4.2.2.2 Grouping of Datalink Technologies

Datalink technologies enable the transfer of digitized information to support communication, navigation and surveillance applications. While different types of datalink technology exist, as illustrated in Figure 48, this research only considers air/ground and ground/ground datalink technologies. Air/ground technologies are further divided into

- Current Air/Ground Datalink Broadcast Technologies (Universal Access Transceiver (UAT), 1090 Extended Squitter (ES), etc.)
- Next Generation of Air/Ground Datalink Broadcast Technologies (Very High Frequency Data Link Mode 4 (VDL4), etc.)
- Current Air/Ground Point-to-point Technologies (High Frequency Data Link (HFDL), Very High Frequency Data Link Mode 2 (VDL2), etc.)
- Next Generation of Air/Ground Datalink Point-to-point Technologies (Very High Frequency Data Link Mode 3 and 4 (VDL3 and VDL4), etc.)

Ground/ground communication, on the other hand, encompasses enablers such as ground IP network, airport wireless communication infrastructure, ground integrated voice/data network, etc.

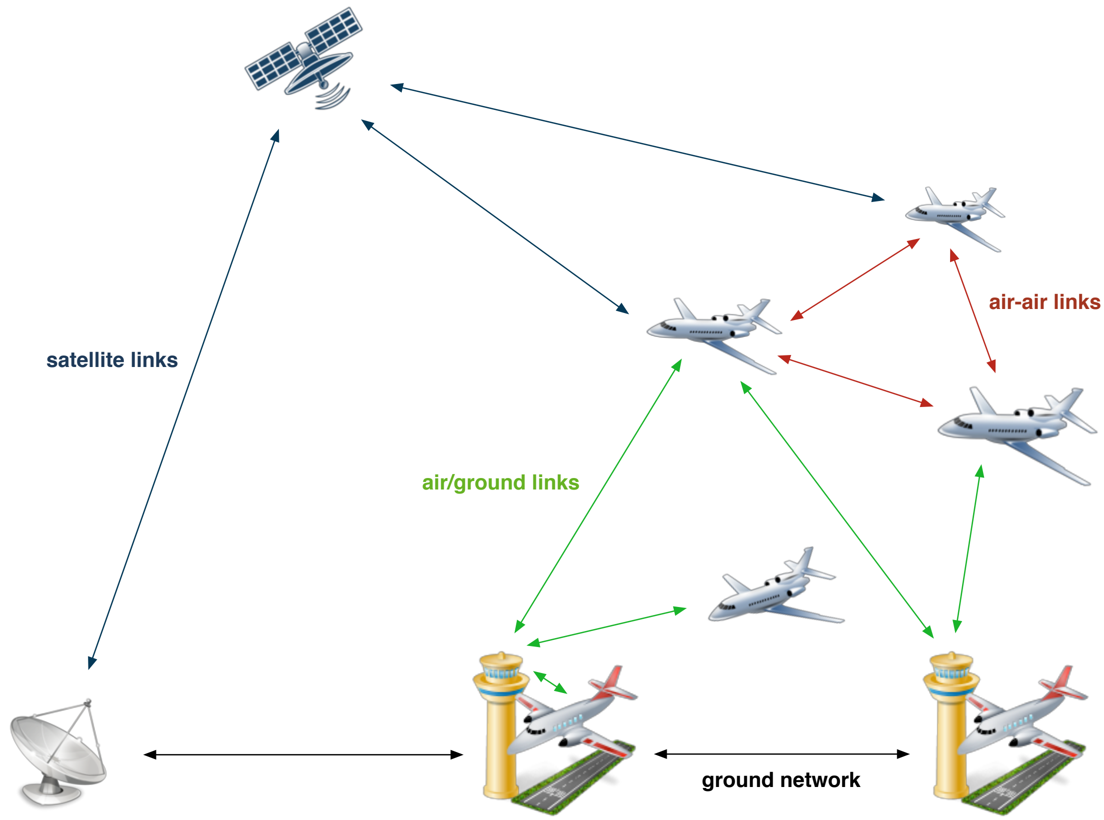


Figure 48: Different types of datalinks (adapted from [269]).

Finally, some enablers can be broken down to better reflect the options available to the airport manager. This is the case, for example, of the enabler *CTE-N11: New Lighting Technology* which, after consideration, is further broken down into *Approach Lighting System* (ex: Medium-intensity Approach Lighting System with Runway Alignment Indicator Lights (MALSR), Approach Lighting System with Sequenced Flashing Lights configuration 1 & 2 (ALSF-1 -2), etc.) and *On Runway Light Systems* (ex: Runway End Identifier Lights (REIL), Touchdown Zone Lights (TDZL), and High Intensity Runway Lights (HIRL), etc.).

Eventually the final set considered in this research includes 41 operational improvements, 5 functions and 36 technologies, as summarized in Tables 16 and 17. These technologies are articulated around the need to increase/improve the efficiency of surface operations under low/near-zero visibility conditions, increase throughput at towered and non-towered airports, provide/increase situational awareness, prevent runway incursion, and support/manage departure, arrival and surface operations. The respective mappings and dependencies can be found in Appendix B, along with a short description of each technology considered.

The resulting implementation of relevance tree analysis, morphological analysis, filters and dependency tables illustrated in Figure 49 thus helps understand interrelationships between improvements, concepts, functions and technologies. The first matrix proposes a set of options for each of the traffic phases of interest. The following matrices are then populated based on option(s) selected in the previous layer. Hence, if the only improvements checked in the first matrix are "*Improve Operations in Adverse Conditions*" and "*Increase Awareness of Traffic Situation on Ground*", then the second matrix will only display Operational Concepts identified as supporting these improvements. This logic is followed all the way down to the fourth matrix, which only displays the technologies for the improvements, concepts and functions selected. Finally, options can be filtered (first panel in Fig. 49) based on operational capabilities (when a technology will enter into service or be operational). The details regarding the technical and computational development of the environment partially illustrated in Figure 49 are further discussed in Chapter 6 Section 6.3.2 of this document.

Table 16: List of the technologies considered and their functions

ID	Technology Name	Function
T_0	Multi-Sensor Data Processor (MSDP)	Surveillance
T_1	Primary Surveillance Radar (PSR)	Surveillance
T_2	Automatic Dependent Surveillance-Broadcast (ADS-B) Out	Surveillance
T_3	Multilateration (MLAT)	Surveillance
T_4	Surface Movement Radar (SMR)	Surveillance
T_5	Legacy Secondary Surveillance Radar (SSR)	Surveillance
T_6	Wide Area Multi-Lateration (WAM)	Surveillance
T_7	Back-up Surveillance System Replacement for the Mode S Beacon System and ATC Beacon	Surveillance
T_8	Next Generation Secondary Surveillance Radar (ex: Air Traffic Control Beacon Interrogator Model 6 (ATCBI-6))	Surveillance
T_9	Airport Surveillance Video	Surveillance
T_{10}	Human Machine Interface (HMI) related Technologies	Surveillance Control/Monitoring Routing/Planning
T_{11}	Ground/Ground Communication	Surveillance Routing/Planning Communication
T_{12}	Surface Movement Control Workstation Equipped with a Wind Shear Monitoring Tool	Control/Monitoring
T_{13}	Surface Movement Control Workstation Equipped with Initial Tools for Resolution of Surface Conflicts	Control/Monitoring
T_{14}	Surface Movement Control Workstation Equipped with Tools for Runway Incursion Detection and Alerting	Control/Monitoring
T_{15}	Surface Movement Control Workstation Equipped with Initial Tools for Aerodrome Control Service	Control/Monitoring
T_{16}	Precision Runway Monitor (PRM)	Control/Monitoring
T_{17}	Surface Movement Control Workstation Enhanced to Use and Display Aircraft-Derived Information	Control/Monitoring
T_{18}	On Runway Light System	Guidance/Navigation
T_{19}	Microwave Landing System (MLS)	Guidance/Navigation
T_{20}	Airfield Lighting Control System	Guidance/Navigation
T_{21}	Switchable Center Line Lights and Stop Bars	Guidance/Navigation
T_{22}	Approach Lighting System (ALS)	Guidance/Navigation
T_{23}	Airport Vehicle Equipped with Static Airport Map Display	Guidance/Navigation
T_{24}	Next Generation Lighting Systems	Guidance/Navigation
T_{25}	Ground-based Augmentation System (GBAS)/Local Area Augmentation System (LAAS) for CAT I	Guidance/Navigation
T_{26}	Ground-based Augmentation System (GBAS)/Local Area Augmentation System (LAAS) for CAT III	Guidance/Navigation
T_{27}	Instrument Landing System (ILS)	Guidance/Navigation

Table 17: List of the technologies considered and their functions (continued).

ID	Technology Name	Function
T_{28}	Departure MANager (DMAN)	Routing/Planning
T_{29}	Surface MANager (SMAN)	Routing/Planning
T_{30}	Arrival MANager (AMAN)	Routing/Planning
T_{31}	Current Air/Ground Datalink Broadcast Technologies	Communication
T_{32}	Current Air/Ground Datalink Point-to-point Technologies	Communication
T_{33}	Next Generation of Air/Ground Datalink Broadcast Technologies	Communication
T_{34}	Next Generation of Air/Ground Datalink Point-to-Point Technologies	Communication
T_{35}	Airport Vehicles Equipped with Two-Way Mobile Communications	Communication

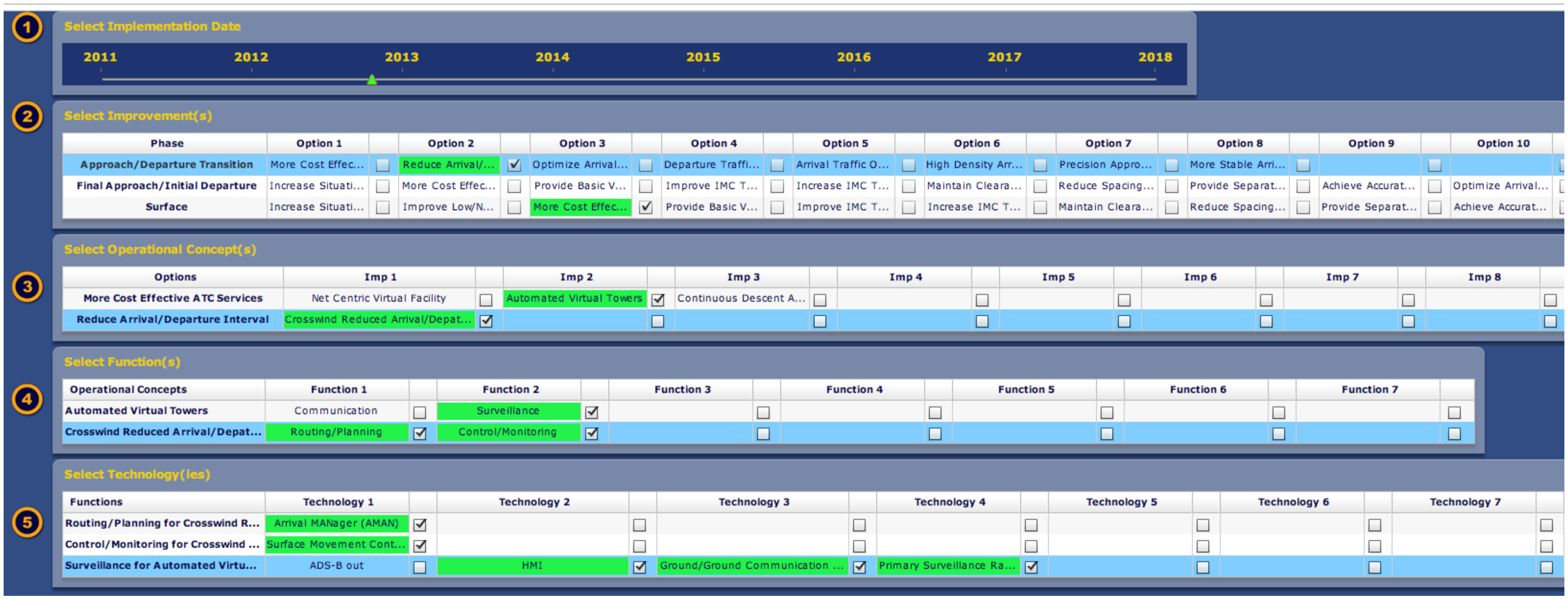


Figure 49: Proposed implementation of decomposition techniques, dependency mapping, and filtering capabilities.

The implementation of relevance tree analysis and morphological analysis, along with filters and dependency tables to support technology selection has been thoroughly described and illustrated through this first step of the proposed methodology. However the ability of these underlying methods to enable a rigorous, structured, and traceable process for technology selection, as hypothesized in Section 2.2, remains to be discussed. This discussion is provided below as a means to support Hypothesis 1.1.

4.3 Discussion on Hypothesis 1.1

Hypothesis 1.1: The combination of decomposition techniques such as relevance tree analysis, and morphological analysis, along with filters and dependency tables provides the decision-maker with a rigorous, structured, and traceable process for technology selection

Verifying Hypothesis 1.1 first calls for a definition of the terms used to characterized the technology selection process. Such definitions are provided below:

4.3.1 Definitions

- *Rigorous:* "A proof or demonstration is said to be rigorous if the validity of each step and the connections between the steps is explicitly made clear in such a way that the result follows with certainty."[333]

- *Structured:* "having and manifesting a clearly defined structure or organization." [80], with *Structure* being defined as "the arrangement of and relations between the parts or elements of something complex" [139]

- *Traceable:* "capable of being traced"[81], with *Traced* being defined as "followed or studied out in detail or step by step" [219]

Verifying Hypothesis 1.1 then requires a discussion on the ability of the combined methods and techniques mentioned above to satisfy these characteristics.

4.3.2 Discussion

Rigorous: The rigorous character of the technology selection process is first supported by the choice of the methods/techniques chosen. Indeed, both relevance tree analysis and morphological analysis have been extensively and successfully implemented for problems of similar complexity. Their validity is also widely established and recognized by the community, as discussed at length in Section 2.2. Second, the steps leading to the proposed process for technology selection, along with their connections, are clearly and explicitly enunciated and described, allowing the user to follow the said process and the logic behind it. Figure 50 further illustrates how the implementation of relevance tree analysis, morphological analysis and dependency tables support it. Third the alternatives provided at each level of the decomposition (Select Improvement(s), Select Operational Concept(s), Select Function(s), etc.) originates from a transparent approach encompassing the gathering, identification and grouping of the relevant information. In other words, the alternatives presented to the decision maker are not provided at random but come from a thorough review, comparison [254], integration and understanding of the underlying relationships and similarities between the options described by both NextGen and SESAR programs. Consequently the aforementioned process, which stems from the combination of the methods and from the integration of the information presented at each level, satisfies the definition of "*rigorous*".

Structured: The structured character of the proposed process is supported by the nature of the methods/techniques that define it:

- Morphological analysis enables the structured, functional, and intelligent decomposition of the problem, as well as the creation of alternatives for each level of the decomposition

- Relevance tree analysis provides the tree-like hierarchical structure [77] that supports

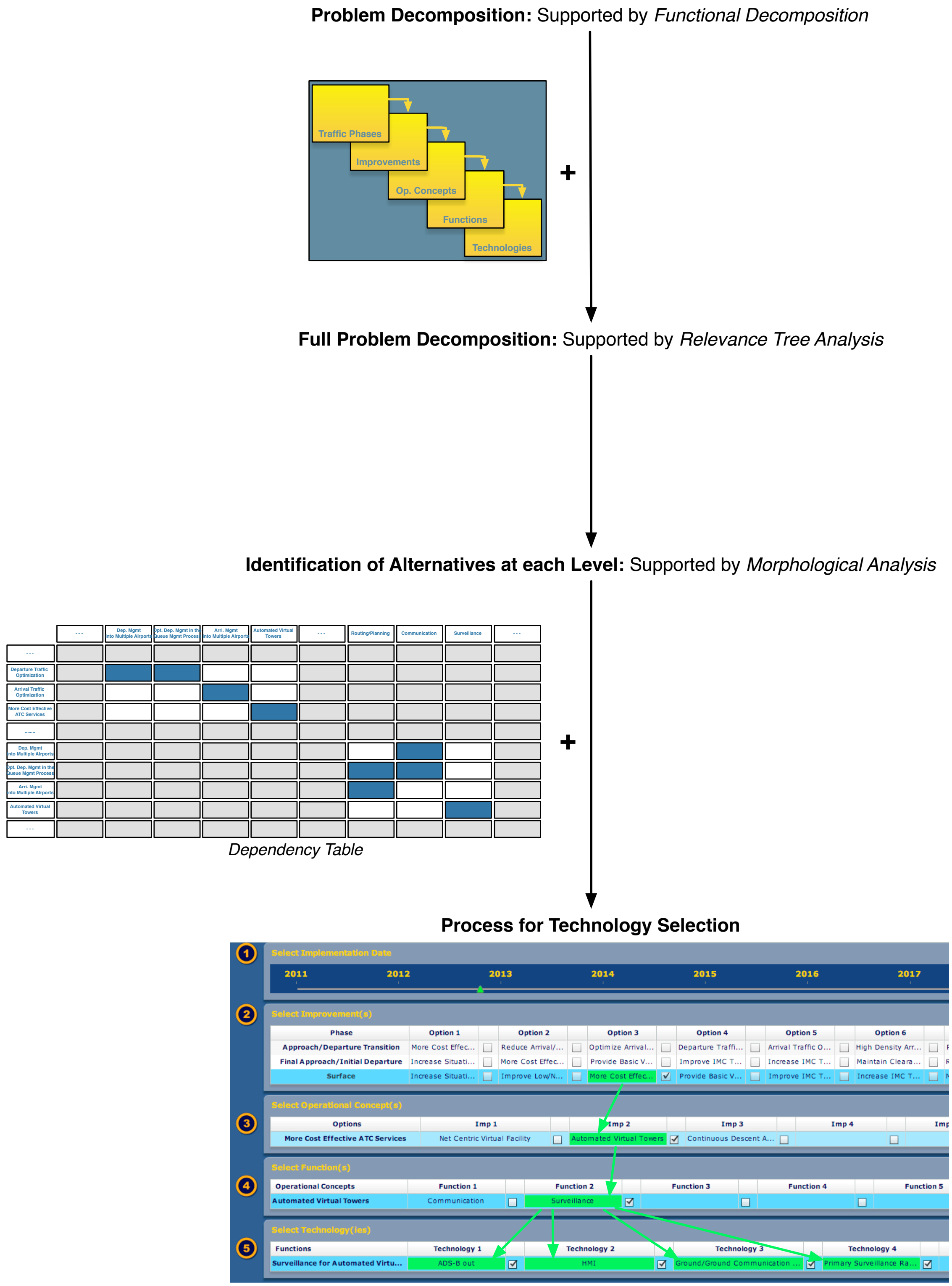


Figure 50: Process overview.

this decomposition

- Dependency tables define the relationships between alternatives from each level (improvement, concept, function and technology levels)

Figure 51 illustrates how, for a subset of alternatives for each step, the methods/techniques used for this problem provide structure to the selection process. Moreover, the process leading to technology selection is clearly defined and organized, as illustrated multiple times throughout Section 4. In particular, the proposed multi-level decomposition is supported by the structure and logic of both NextGen and SESAR programs. Hence, the proposed process also satisfies the definition of "*structured*".

Traceable: The traceable character of the technology selection process is mainly supported by the implementation of dependency tables. In particular, the definition and integration of dependencies within the selection process, as illustrated in Figure 51, enable the decision maker to quickly identify and interactively visualize, by means of cascading morphological matrices, the options that led to the technologies proposed (Figure 52). These dependencies stem from the multi-level decomposition illustrated in Figure 42 (and supported by both morphological analysis and relevance tree analysis), as well as from a thorough review of the underlying relationships between improvements, concepts, functions and technologies. The traceability of the process is thus satisfied, as further illustrated by Figure 52.

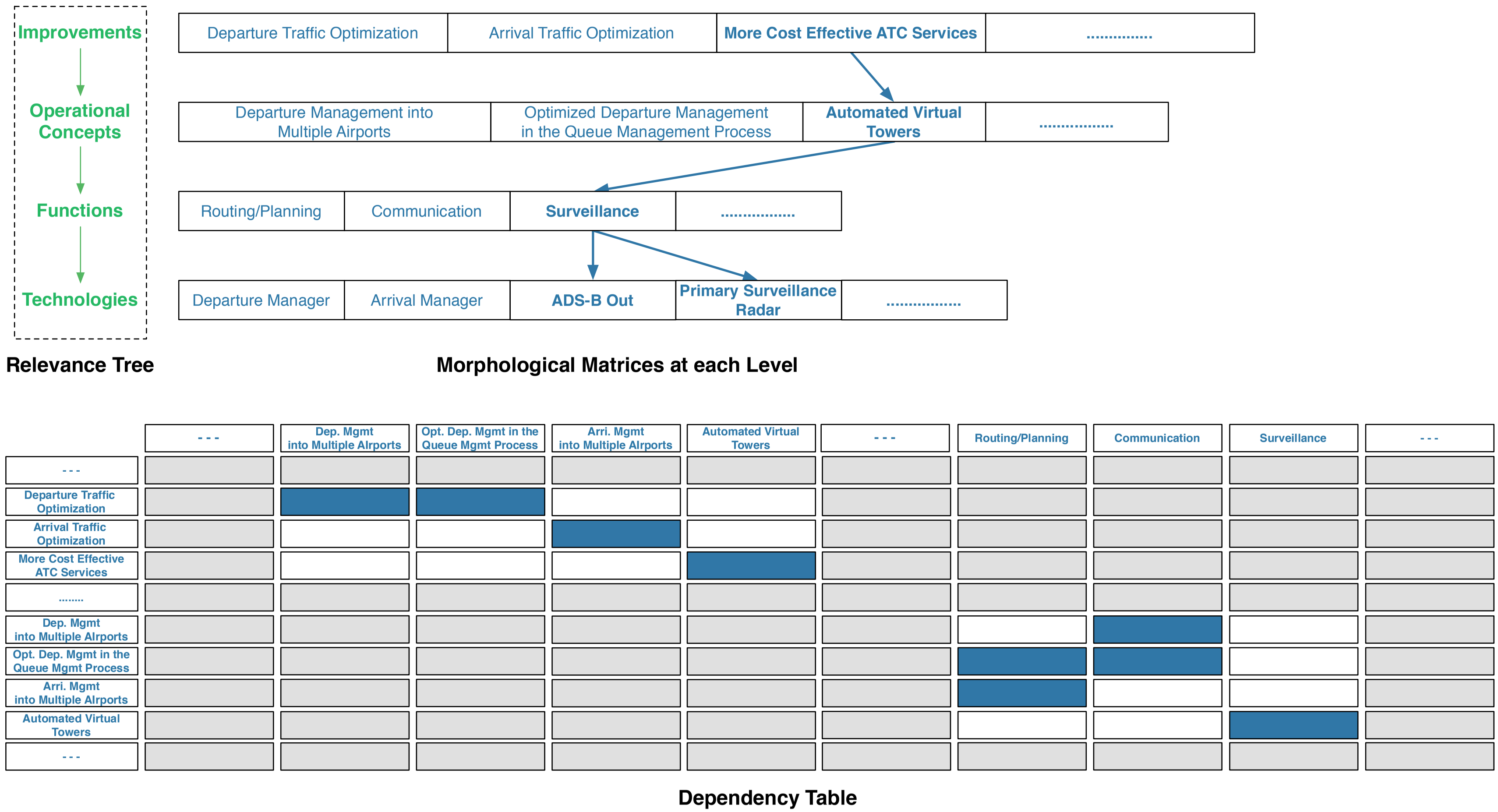


Figure 51: Example of the use of the decomposition techniques.

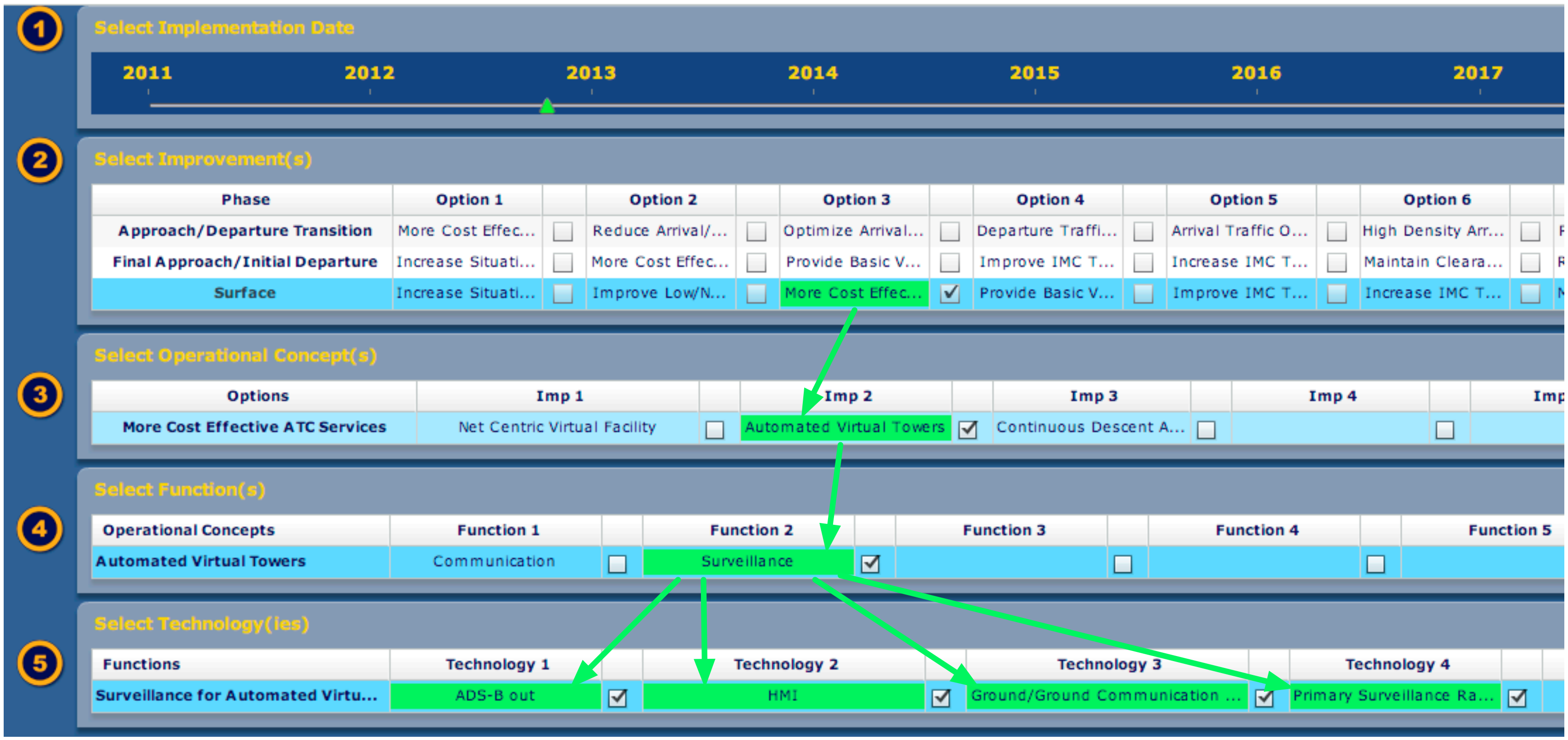


Figure 52: Illustration of the traceability characteristic.

4.3.3 Hypothesis Verification

As discussed above, the implementation of relevance tree analysis and morphological analysis, along with filters and dependency tables to support technology selection has shown to enable a rigorous, structured, and traceable process for technology selection. Consequently, **Hypothesis 1.1 is verified**.

This first step allows the decision-maker to either pick specific technologies of interest, or select all technologies available at a desired deployment date. In both cases, these technologies constitute an initial pool from which portfolios can be formulated. However, as previously discussed, good investment decisions cannot be made without assessing the impact of the selected technologies on the performance of the system. Additionally, adaptable portfolios cannot be formulated, without a prior understanding of the technologies in the context of their relationships with one another. The second step of this proposed approach addresses these aspects.

CHAPTER V

STEP #2: TECHNOLOGY IMPACT ASSESSMENT

Determining the causal relationships between technologies is essential to the future definition of portfolios. Cross-Impact Analysis was identified among various methods as the one being the most susceptible, for the problem of interest, to provide information regarding causal impacts and complex relations among technologies. The following section describes how the approach advocated by Choi et al. [56] can be implemented for the problem at hand.

5.1 Step 2a: Definition of Technology Influence Scores

In their paper, Choi et al. developed a methodology to study the relationships and impact between technologies using patent registration, classification, and information. In this research, we propose to define a *Technology Influence Score* using the interdependencies at the operational improvement and technology levels obtained during Step #1. In the context of this work, the Influence Score of Technology A on Technology B is thus defined by N(A): the number of operational improvements requiring technology A, and N(A ∩ B): the number of operational improvements requiring both technologies A and B, as illustrated by Equation 5. Similarly, the influence of Technology B on Technology A is provided by Equation 6. As a reminder, $P(B \setminus A)$ represents the probability that event B occurs conditional on event A having occured. Technology Influence Scores can thus be understood as follows: "If $Influence(A, B) = x$, then x percent of all operational improvements requiring Technology A, also require Technology B."

$$Influence(A, B) = P(B \setminus A) = \frac{N(A \cap B)}{N(A)} \tag{5}$$

$$Influence(B, A) = P(A \setminus B) = \frac{N(A \cap B)}{N(B)} \tag{6}$$

The implementation of this approach to the set of operational improvements and technologies considered in this research is described in the following section.

5.1.1 Implementation

Technology Influence Scores are computed for each technology pair using Equations 5 and 6. The Technology Influence Scores obtained are then plotted against one another on a Technology Influence Map, as illustrated in Figure 53. However, no clear threshold or cutoff value to differentiate between the different relationships (uni-, bi-directional or no influence) for the technologies considered can be identified from this figure. This, as acknowledged by Choi et al., is a known issue of this approach. As an attempt to address this concern, Technology Influence Scores are then computed and plotted for technologies enabling similar functions separately. Also, because technology relationships are investigated at the functional level, only one level of dependency between technologies is considered. As a matter of fact, considering higher levels of dependency would result in the computation of Technology Influence Scores across functions. It would also require that a particular effort be made to ensure that technologies are not accounted for twice, as one technology could be present at different levels.

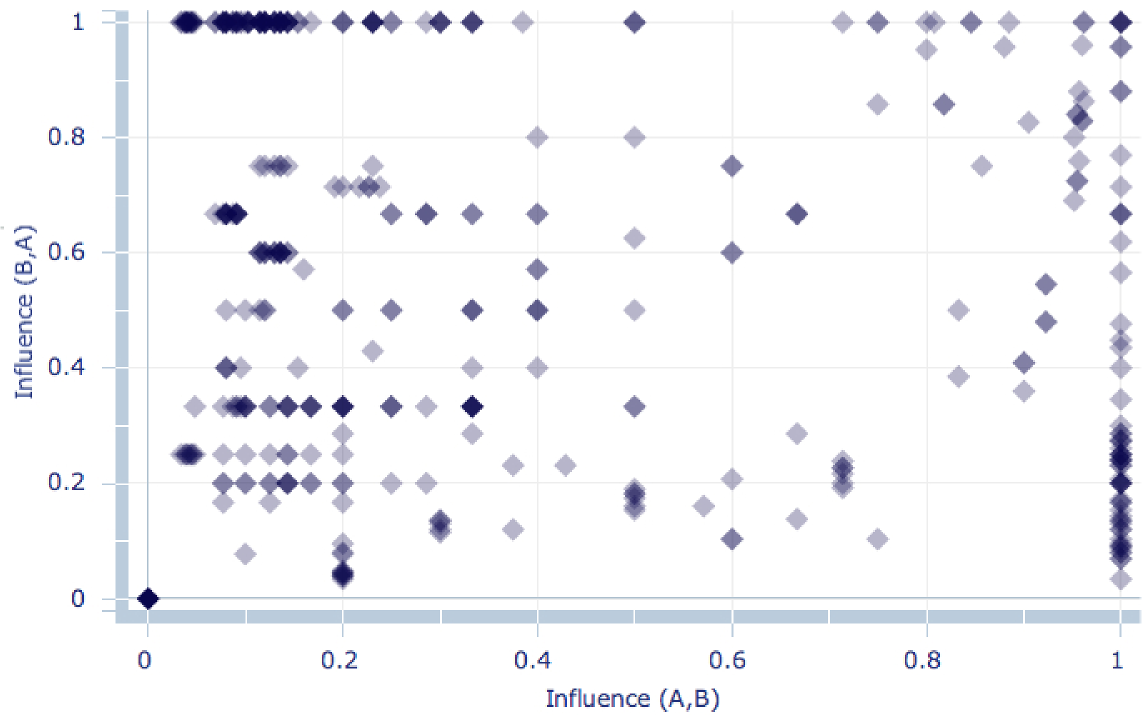
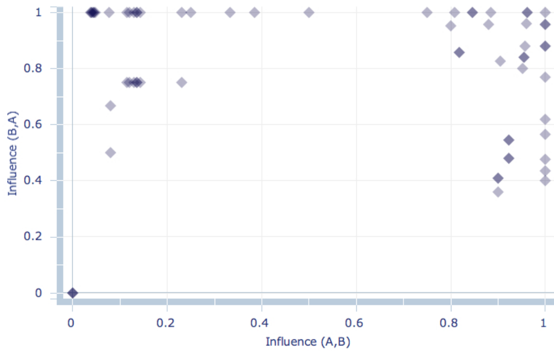
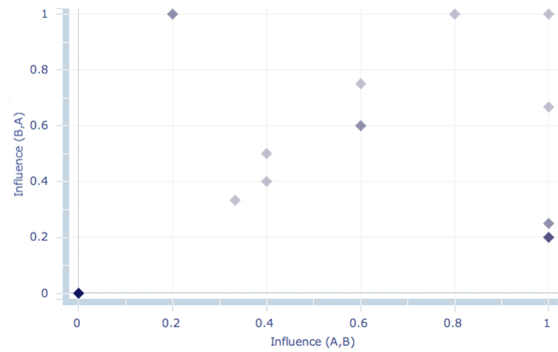


Figure 53: Technology Influence Scores for all technologies independently of their respective functions.

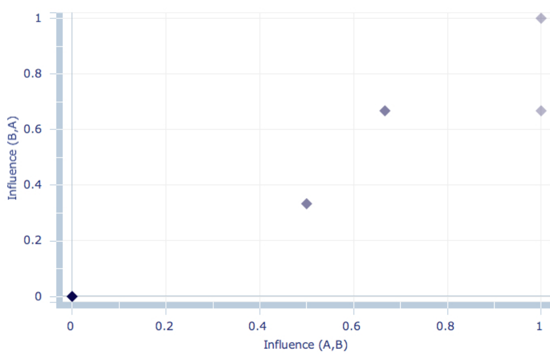
As illustrated by Figures 54(a) to 54(e), plotting Technology Influence Scores for each function independently allows to better highlight technology groupings.



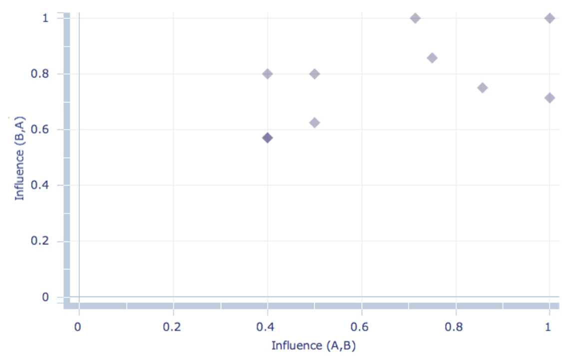
(a) Surveillance technologies.



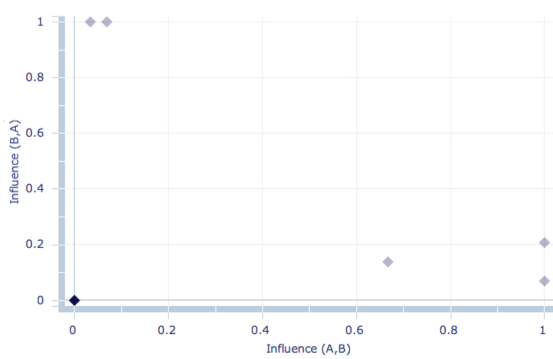
(b) Guidance/Navigation technologies.



(c) Control/Monitoring technologies.



(d) Routing/Planning technologies.



(e) Communication technologies.

Figure 54: Technology Influence Map for each function.

More importantly, these figures provide a way to instantaneously visualize and review all the information contained in the mappings (Figure 55), identify Technology Influence Scores and technology relationships that seem inaccurate or do not properly capture known/expected dependencies, and modify inaccurate mappings based on additional information and knowledge gathered from the relevant literature. Once the mappings are modified, Technology Influence Scores are again automatically plotted against one another until they better represent the technology relationships. For instance, some mappings were modified to capture the fact that a Microwave Landing System (MLS) is intended to replace or complement an Instrument Landing System (ILS) or that non-cooperative independent surveillance (Primary Surveillance Radar) is required when deploying ADS-B or Multilateration (MLAT).

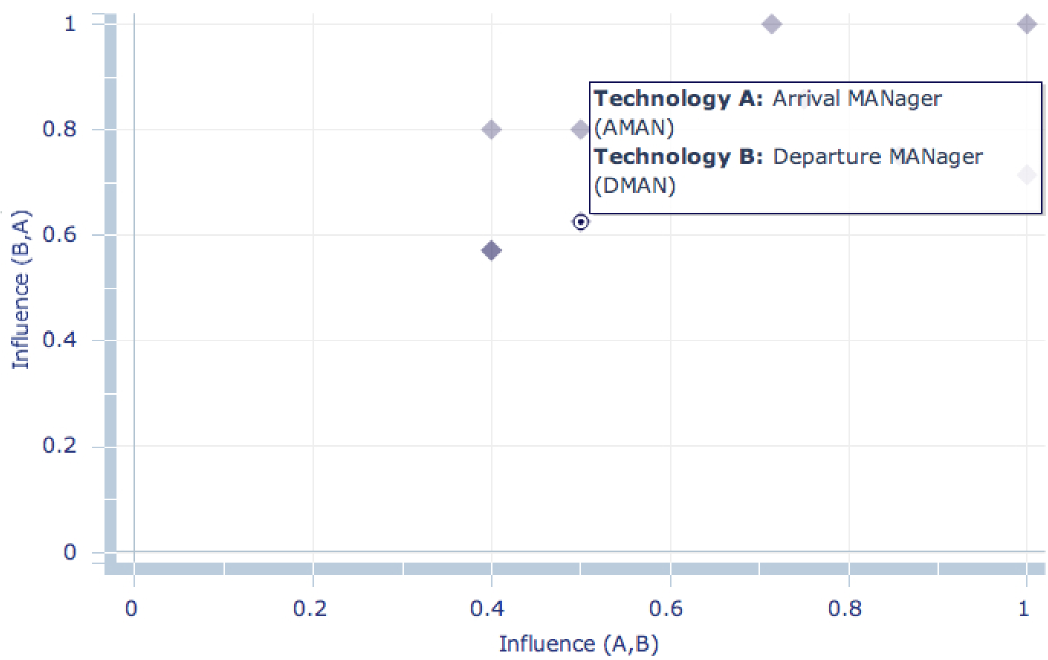


Figure 55: An instantaneous means to visualize technology relationships.

5.1.1.1 Accounting for Cross-Functional Influence

Some technology groupings fulfill multiple functions. Technologies responsible for the exchange and visualization of data/information, in particular, tend to be required by different functions. Hence, technologies supporting ground/ground communication may be necessary for Surveillance purposes, as well as for Routing/Planning ones. However, the technologies enabling ground/ground communication for the Surveillance function may be different from the ones supporting the Routing/Planning function. To alleviate this concern, and for simplification purposes, a same "grouping" name was used across the different functions for technologies belonging to that same grouping (Figure 56). In other words, this means that a unique name is used for different technologies (as long as they are part of the same grouping). Hence, it is assumed that the equipment provider will advise the airport manager regarding which ground/ground communication technology(ies), for example, a specific function would require.

5.1.1.2 Identifying and Understanding Technology Relationships

As illustrated in Figure 57, the nature of the relationship between two technologies can be rapidly identified from a Technology Influence Map. Hence, if both $Influence(A,B)$ and $Influence(B,A)$ are high, then Technologies A and B have a bi-directional influence, meaning that Technologies A and B can collaborate and complement each other. This is for example the case of an Arrival Manager (AMAN) and a Departure MANager (DMAN), whose functionalities can be integrated. If $Influence(A,B)$ is high but $Influence(B,A)$ is low, then the presence of Technology A assumes the presence of Technology B. Inversely, if $Influence(A,B)$ is low but $Influence(A,B)$ is high, then the presence of Technology B assumes the presence of Technology A. Finally, if both $Influence(A,B)$ and $Influence(B,A)$ are low, then Technologies A and B have no influence on one another. The meaning of these relationships directly comes from the equations used to compute $Influence(A,B)$

and $Influence(B, A)$.

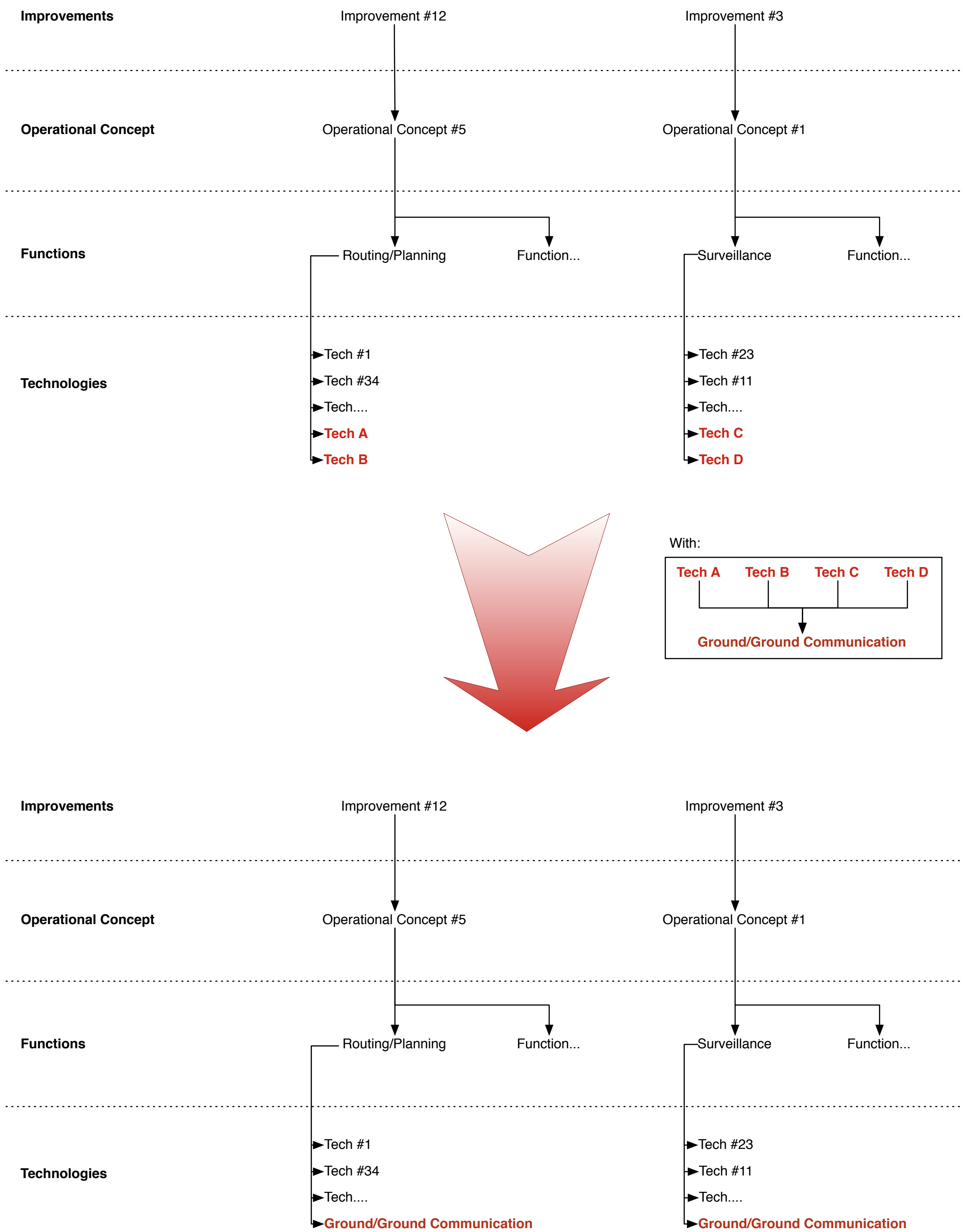


Figure 56: Accounting for cross-functional influence.

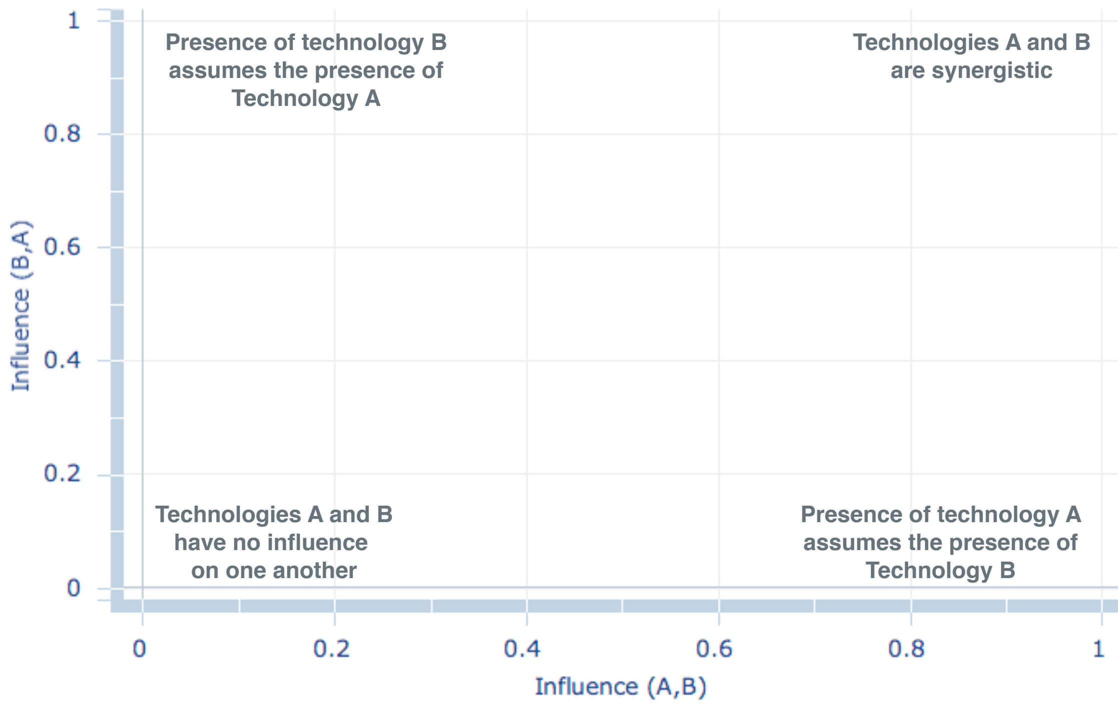


Figure 57: Nature of technology relationships as represented on a Technology Influence Map.

5.1.1.3 Cross Influence Matrices

Tables 18 to 22 summarize the nature of the relationships between technology pairs for each individual function. The information described in each cross influence matrices stems from a careful review of the literature. The meaning of these relationships is illustrated in Figure 58.

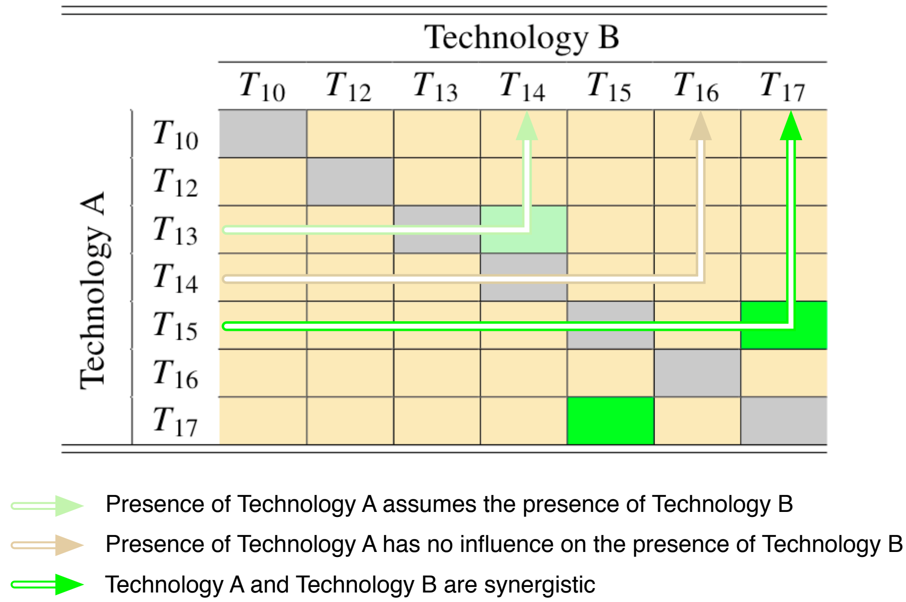


Figure 58: Types of relationships depicted in a Cross Influence Matrix.

Table 18: Cross Influence Matrix for the Surveillance technologies

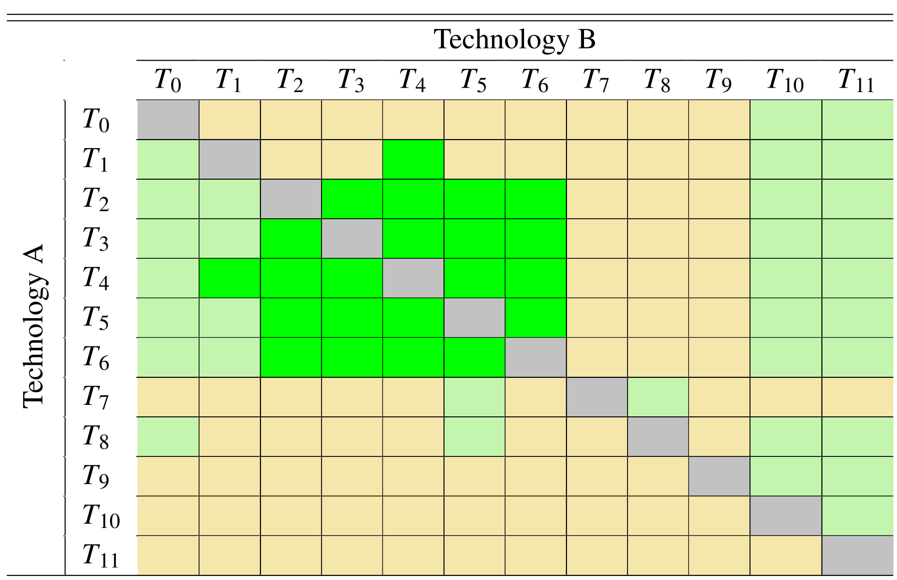


Table 19: Cross Influence Matrix for the Control/Monitoring technologies.

		Technology B						
		T_{10}	T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}
Technology A	T_{10}							
	T_{12}							
	T_{13}							
	T_{14}							
	T_{15}							
	T_{16}							
	T_{17}							

Table 20: Cross Influence Matrix for the Guidance/Navigation technologies.

		Technology B									
		T_{18}	T_{19}	T_{20}	T_{21}	T_{22}	T_{23}	T_{24}	T_{25}	T_{26}	T_{27}
Technology A	T_{18}										
	T_{19}										
	T_{20}										
	T_{21}										
	T_{22}										
	T_{23}										
	T_{24}										
	T_{25}										
	T_{26}										
	T_{27}										

Table 21: Cross Influence Matrix for the Routing/Planning technologies.

		Technology B				
		T_{10}	T_{11}	T_{28}	T_{29}	T_{30}
Technology A	T_{10}					
	T_{11}					
	T_{28}					
	T_{29}					
	T_{30}					

Table 22: Cross Influence Matrix for the Communication technologies.

		Technology B					
		T_{11}	T_{31}	T_{32}	T_{33}	T_{34}	T_{35}
Technology A	T_{11}						
	T_{31}						
	T_{32}						
	T_{33}						
	T_{34}						
	T_{35}						

For comparison purposes, Figures 59 to 63 illustrate the overlapping of the information contained in each Cross Influence Matrix with the respective data points provided through the computation of Equations 5 and 6. A potential cutoff value (threshold) is identified when possible (Figures 60(b), 61(b) and 63(b)). From Figures 59 to 63, it is apparent that some of the technology relationships defined in the Cross Influence Matrices do not appear in the proper quadrant when plotted on their respective Technology Influence Map. In particular, Figures 59 and 62 illustrate the difficulty to clearly distinguish between relationship types for functions offering a high level of collaboration and complementarity between their technologies. More importantly, they also demonstrate the inherent complexity of modeling the integration of stand-alone technologies and the incomplete answer provided by Cross Impact Analysis for such purpose. The following paragraphs explain in more detail the reasons for such discrepancies.

5.1.2 Preliminary Remarks

The disparities between the information contained in the Cross Influence Matrices and the data points in Figures 59 to 63 can be explained by the number of technologies considered and their number of occurrences in the mappings. In particular, it appears that careful attention and further investigation are required when technologies occur only once in the set of mappings. Such situations are discussed below.

- Case where a technology is mapped to only one operational improvement:
  - **If both technologies share the same operational improvement:** Let us compute, for example, $Influence(A,B)$ and $Influence(B,A)$ for Technology A: *Multilateration (MLAT)* and Technology B: *Airport Surveillance Video*, with technology B sharing the same function and operational improvement as Technology A but only appearing once in the entire set of mappings. In this case, N(A) is equal to 22, N(B) is equal to 1 and N(A ∩ B) is equal 1. Consequently, from Equations 5 and 6, $Influence(A,B) = 0.045$ and $Influence(B,A) = 1$. This, according to Figure 57, means that the presence of Airport Surveillance Video implies the presence of Multilateration, when in reality these two technologies have no influence on one another. Hence, these numbers, while correct, do not represent the real nature of the relationship between these two technologies. This is further illustrated in Figure 59 where the yellow circles with a thick contour mark Cross Influence Scores between the technology "Airport Video Surveillance" and any other technology. While the position of theses circles on the Cross Influence Map indicate some kind of influence between the technologies described in these pairs, they, in reality, have no influence over one another.
  - **If both technologies do not share any operational improvement:** In this case N(A ∩ B) is equal to 0 and both $Influence(A,B)$ and $Influence(B,A)$ are equal to 0. This represents, as expected, that these two technologies do not influence one another.
- Case where at least two technologies are mapped to only one operational improvement:
  - **If both technologies share the same operational improvement:** The OI descriptions used to create the initial mappings identify technologies that can

be implemented individually or integrated with one another. Consequently, if two technologies are mapped to a same and unique operational improvement and share the same function, then these two technologies can either be synergistic or mutually exclusive. However, in this case, Equations 5 and 6 give $Influence(A, B) = Influence(B, A) = 1$, and thus do not capture the fact that the technologies considered can be mutually exclusive. In such instance, Cross Impact Analysis thus fails to differentiate between synergistic and mutually exclusive technologies. This is the case, for example, of Technology A: *HMI* and Technology B: *Ground/Ground Communication*, which are constantly mapped to the same 9 operational improvements and for which, N(A) = N(B) = N(A ∩ B) = 9 leads to $Influence(A, B) = Influence(B, A) = 1$. As illustrated in Figure 62 both technologies appear on the Cross Influence Map (yellow circle with a thick contour) as synergistic although they are mutually exclusive.

– **If technologies do not share any operational improvement:** In this case N(A ∩ B) is equal to 0 and both $Influence(A, B)$ and $Influence(B, A)$ are equal to 0. This represents, as expected, that these two technologies do not influence one another.

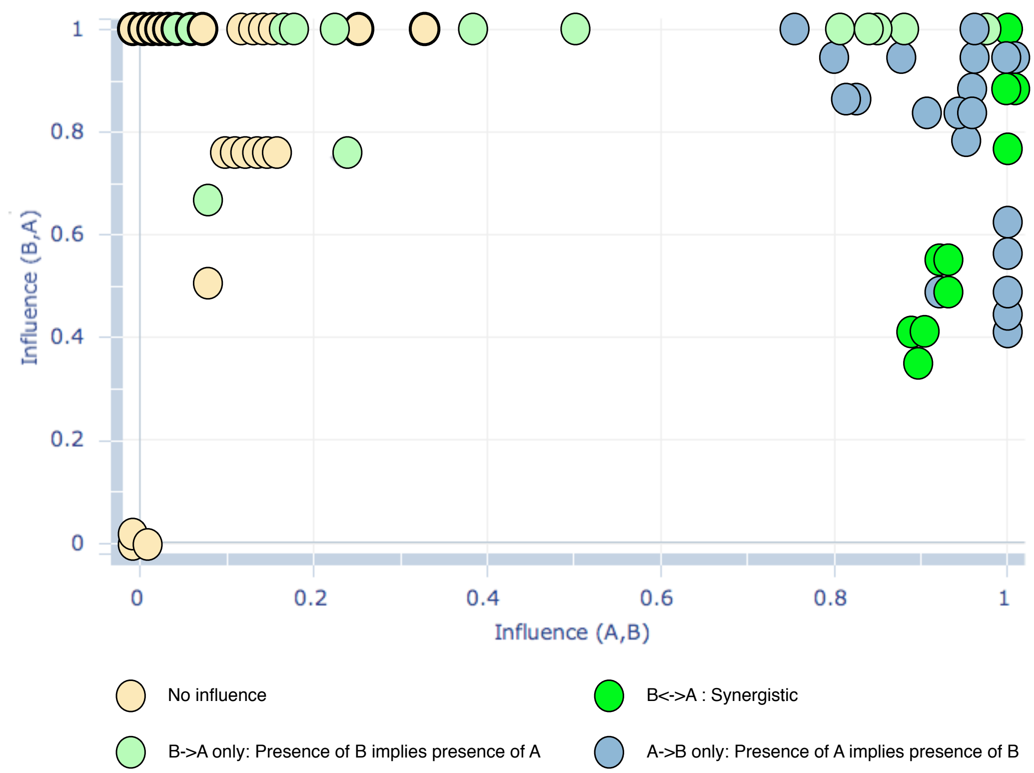
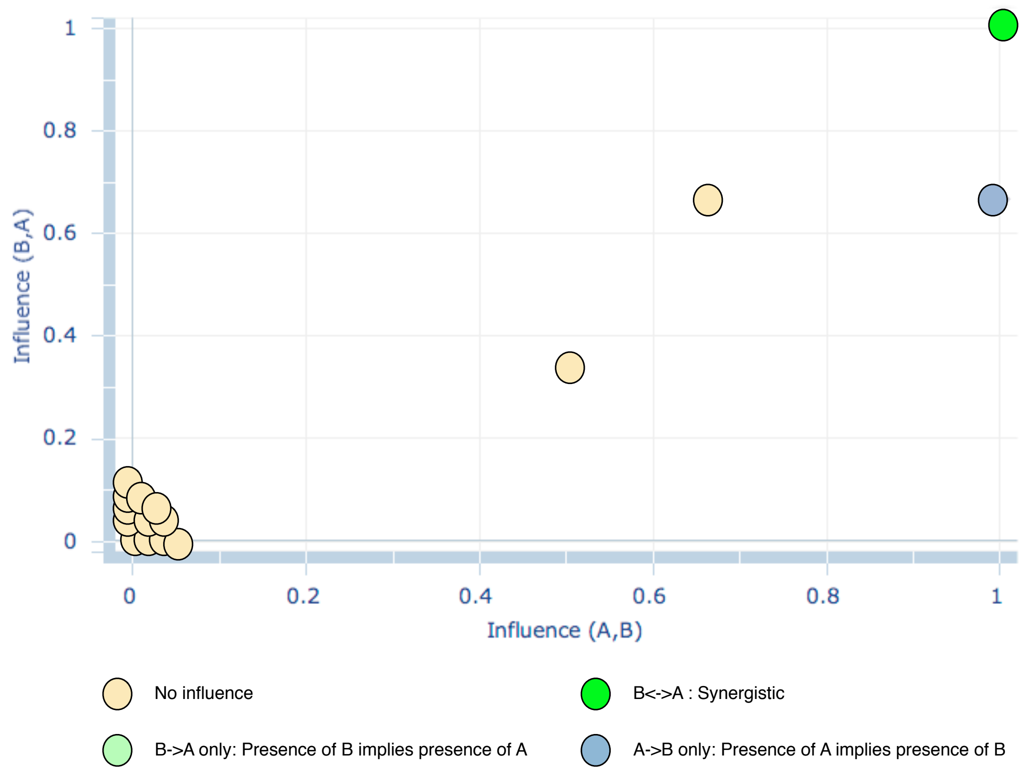
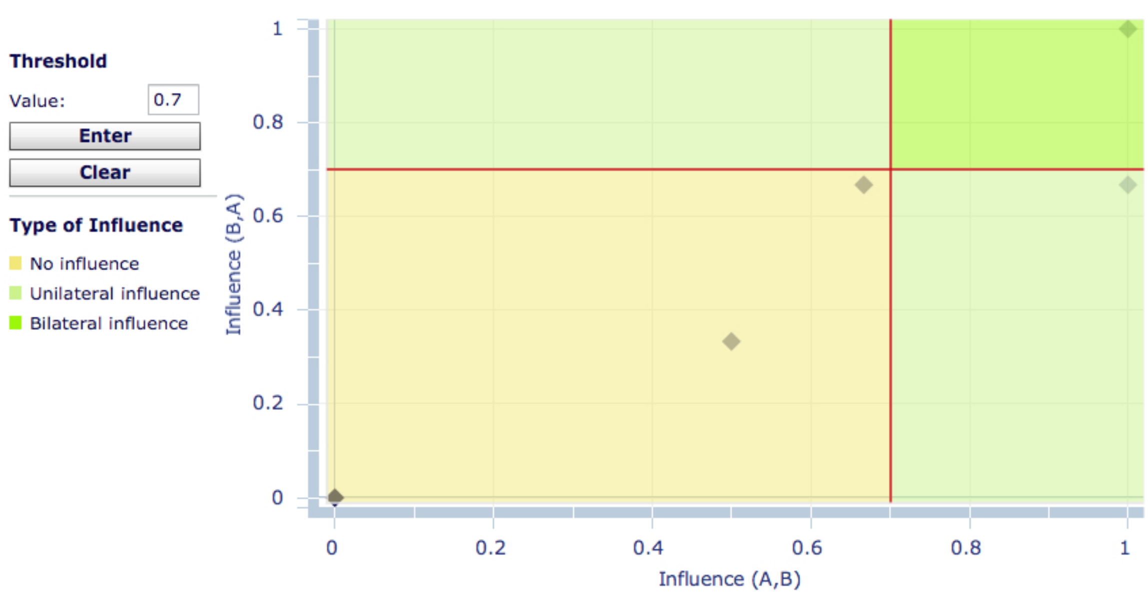


Figure 59: Overlapping of Cross Influence Matrix information for Surveillance technologies - no cutoff value identifiable.

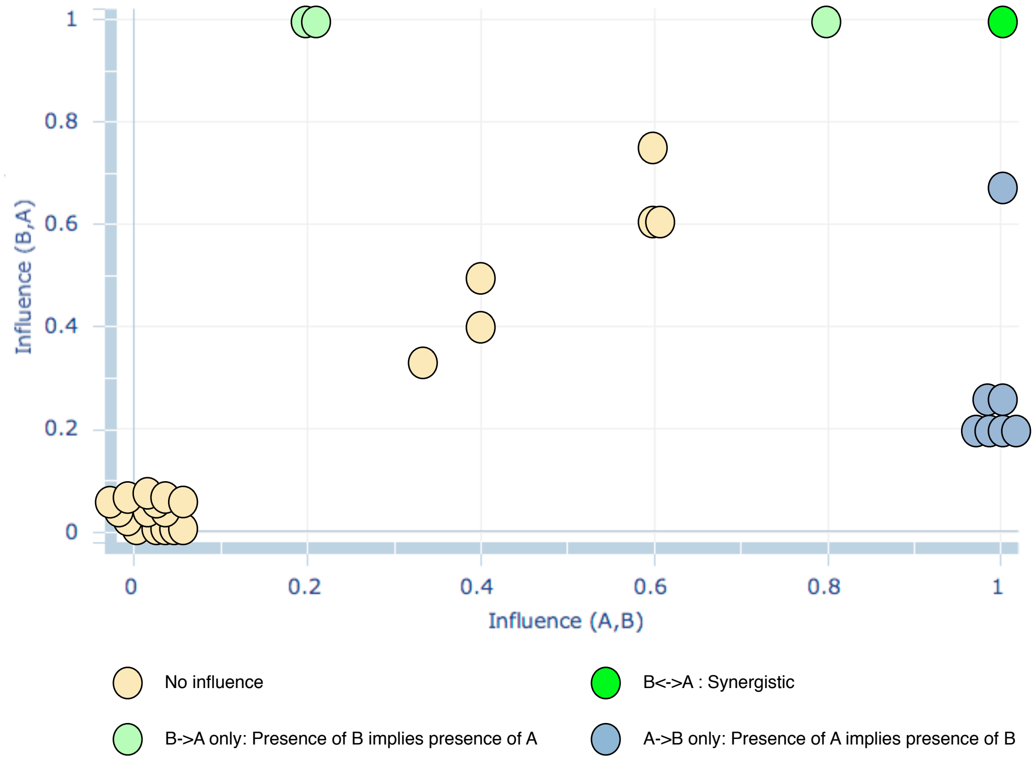


(a) Overlapping

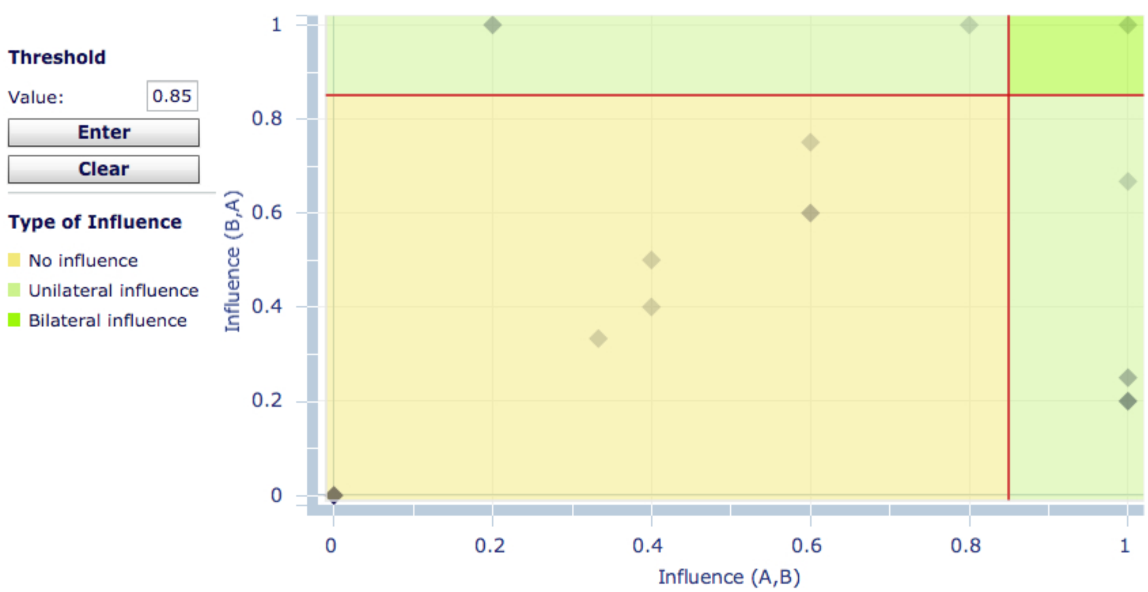


(b) Potential Cutoff Value

Figure 60: Overlapping of Cross Influence Matrix information for Control/Monitoring technologies and potential cutoff value.



(a) Overlapping



(b) Potential Cutoff Value

Figure 61: Overlapping of Cross Influence Matrix information for Guidance/Navigation technologies and potential cutoff value.

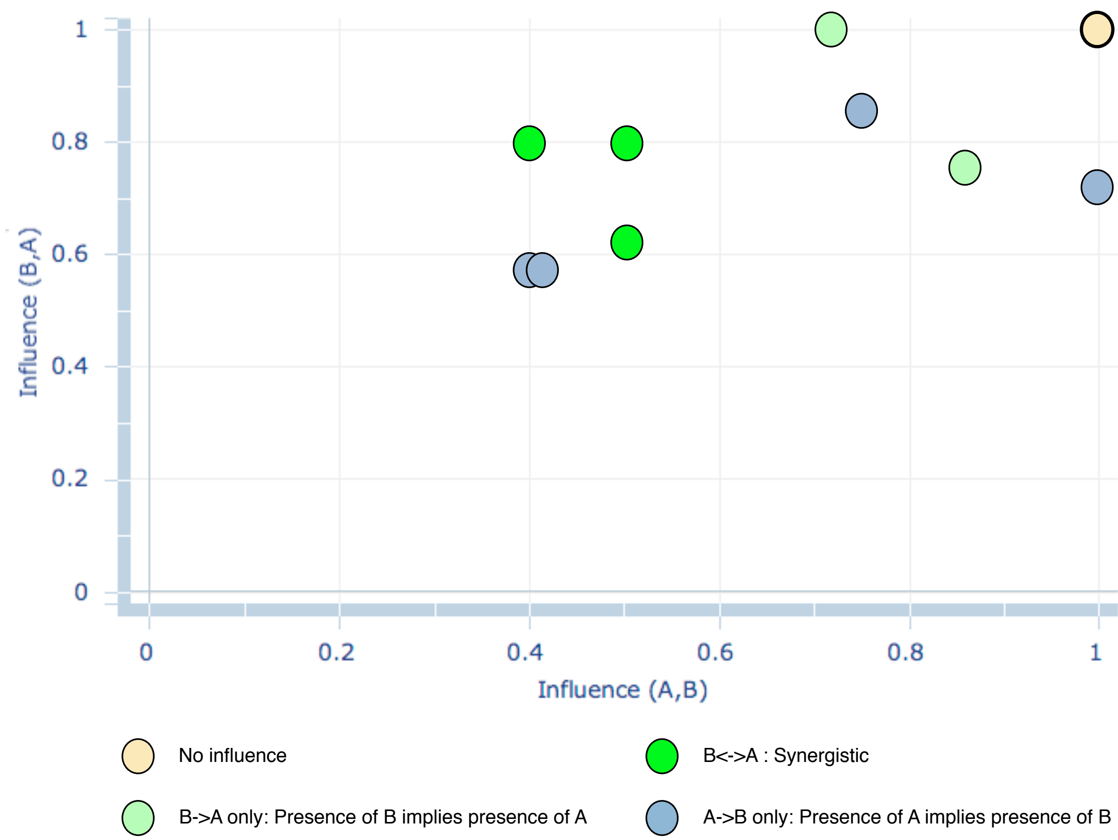
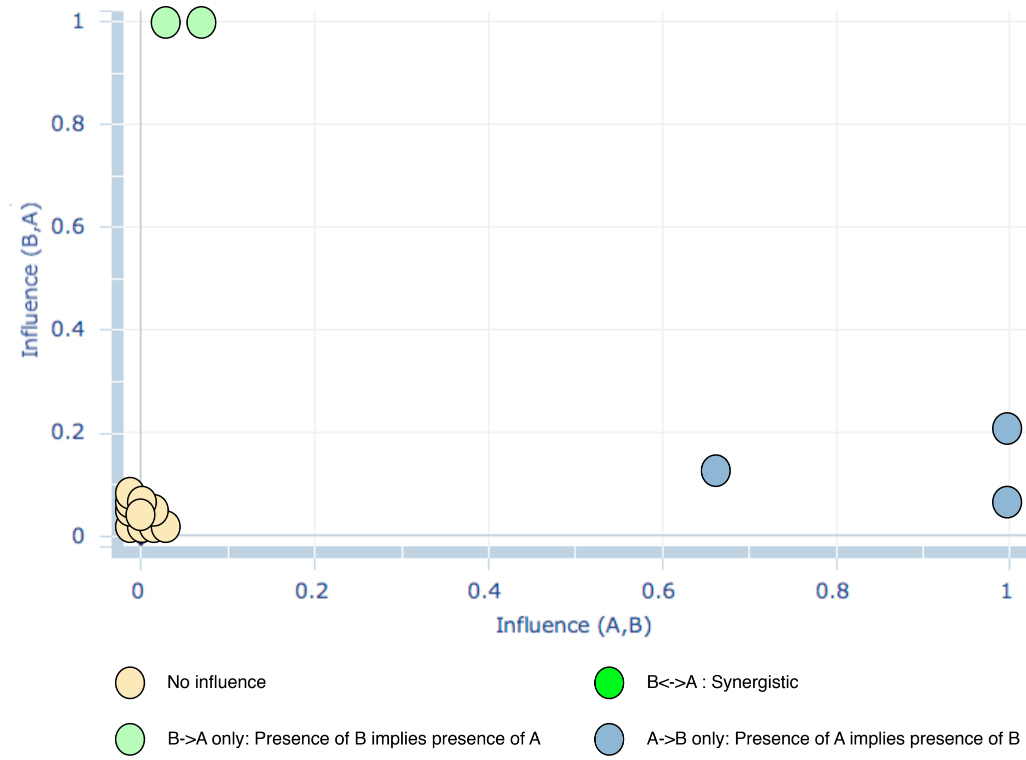
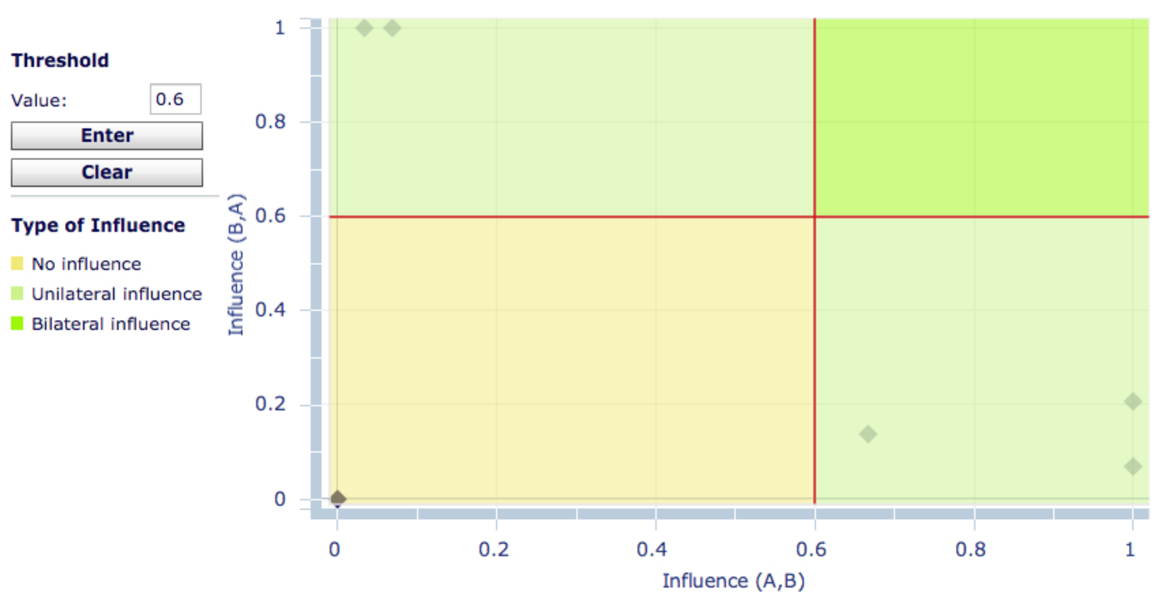


Figure 62: Overlapping of Cross Influence Matrix information for Routing/Planning technologies - no cutoff value identifiable.



(a) Overlapping



(b) Potential Cutoff Value

Figure 63: Overlapping of Cross Influence Matrix information for Communication technologies and potential cutoff value.

As discussed, the implementation of Cross Impact Analysis to capture the true nature of technology relationships is complicated by the fact that some of the technologies considered in this work are only referenced once, or can be complementary and integrated in many different ways (this is particularly true for Surveillance technologies). This makes the identification of a cutoff (or threshold) value for each of these functions particularly difficult, and in some cases, as discussed above, impossible, because there is no straight delimitation between the different types of relationships represented. The following section places these observations in the context of Hypothesis 1.2.

5.1.3 Discussion on Hypothesis 1.2

Hypothesis 1.2: The necessary information regarding causal impacts and complex relations among technologies for the problem of interest can be provided by the implementation of Cross-Impact methods.

A discussion regarding the suitability and feasibility of implementing Cross-Impact Analysis to determine the causality impacts of the set of technologies considered is provided below. This discussion, which is articulated around the limitations and benefits of using CIA to properly identify technology relationships, serves as a means to test Hypothesis 1.2.

Challenges and Limitations

A first issue regarding the implementation of Cross Impact Analysis in the context of this work emanates from the lack of consistency in the OIs' descriptions provided by both NextGen and SESAR. This lack of consistency in the descriptions along with the disparate level of detail and information provided, as illustrated with Figure 64, make the identification of specific technologies and the creation of mappings between operational improvements, functions and technologies challenging.

CTE-N11: New Lightning Technology
The uses of aeronautical ground lighting (AGL) include visual aids to flight crew (e.g., approach lighting, glideslope indication, delineating the runway surface, showing taxiway centre-lines and edges), surface movement control (e.g. the use of red stop bars, the indication of authorised surface routes), alerts (e.g. entering the runway) and manoeuvring aids in the apron area. Light emitting diodes (LEDs) are more energy efficient than currently lighting, which is largely provided by incandescent lamps of varying light output, colour and beam spread characteristics. LEDs have approximately ten to one hundred times the life span of incandescent lamps, are more tolerant of vibration (i.e. in the touch down area) and can generate a greater diversity of colours of specific hues.

Figure 64: Description of enabler CTE-N11[110].

Previous work has also shown that Cross Impact Analysis is particularly suitable when the technologies mentioned are required and when all the technologies required are mentioned (as this is the case with patents). Unfortunately, OIs descriptions often list "types" of technologies (Approach Lighting Systems, etc.) or technologies that can either be implemented individually or integrated with one another, as opposed to unique, specific and required technologies. This makes identifying the nature of technology relationships, when they exist, particularly difficult and necessitates that each relationship described in the Technology Influence Maps be reviewed (as discussed in Section 5.1.1.2), either by means of expert knowledge, or through review of the relevant literature. Along the same lines, the difficulty to clearly distinguish between relationship types for functions offering a high level of collaboration and complementarity between their technologies makes the identification of a threshold value challenging, if not impossible.

The number of OIs and technologies considered in this work also represents a challenge to the implementation of Cross Impact Analysis. While Choi et al. illustrated its use against tens of thousands of patents and thousands of technologies, the number of OIs and technologies considered in this work is limited. Figure 65 shows how $Influence(A,B)$ and $Influence(B,A)$ vary as N(A), N(B) and N(A ∩ B) change. In particular, it illustrates the strong impact of variations in N(A) and N(A ∩ B) on $Influence(A,B)$, when N(A) and

N(A ∩ B) are small (and similarly for the influence of variations in N(B) and N(A ∩ B) on $Influence(B, A)$).

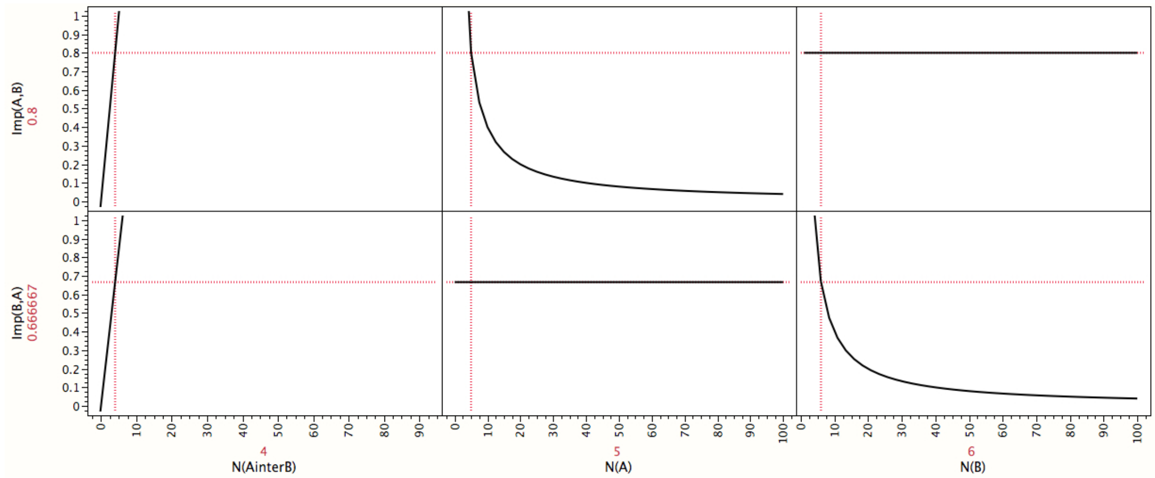


Figure 65: Variations in $Influence(A, B)$ and $Influence(B, A)$ as a function of $N(A \cap B)$, $N(A)$, $N(B)$.

Along the same lines, Figure 66 shows that $Influence(A, B)$ is more sensitive to variations in N(A) (N(A ∩ B) being fixed), when N(A) is small.

Both figures thus show that adding or subtracting technologies to an already relatively small number of technologies dramatically changes the values of both $Influence(A, B)$ and $Influence(B, A)$. In other words, the robustness of a set threshold is highly dependent on the number of technologies used to determine its value: a threshold value based on three or four technologies is likely to require some revision or refinement as more or fewer technologies are considered. As a result, given the relatively small number of technologies represented in this work, Equations 5 and 6 cannot be used to make inferences regarding the nature of technology relationships beyond the two following cases:

- $Influence(A, B) = Influence(B, A) = 0$: the technologies have no influence on one another

- $Influence(A, B) \neq 0$ and $Influence(B, A) \neq 0$: there exist some kind of relationship that needs to be further investigated

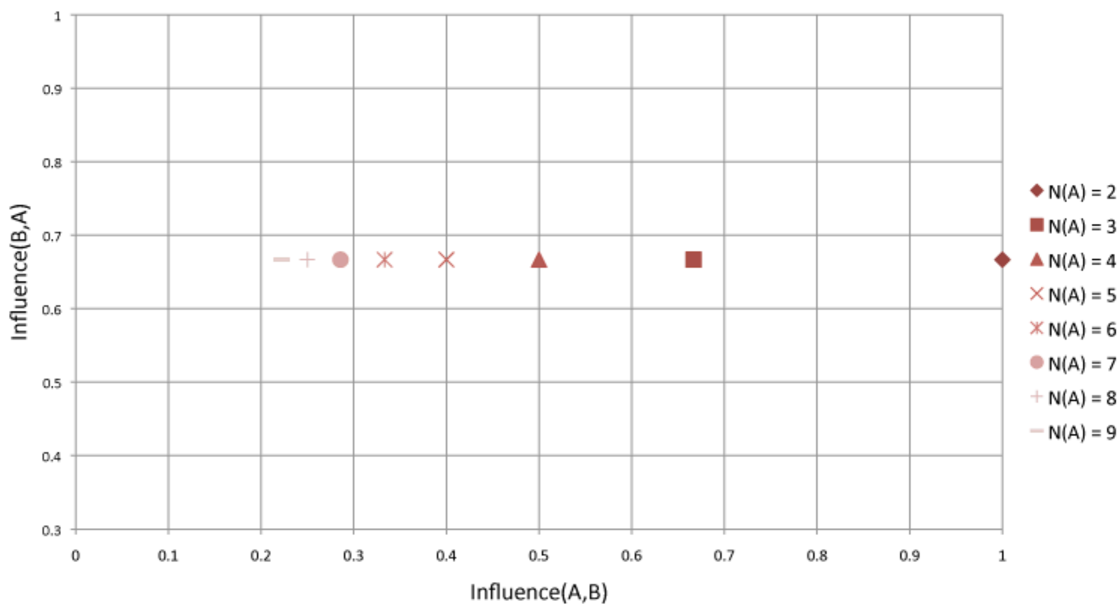


Figure 66: Variations in $Influence(A,B)$ and $Influence(B,A)$ as $N(A)$ varies ($N(A \cap B)$ and $N(B)$ are fixed).

Benefits

Despite its limitations, Cross Impact Analysis presents some interesting benefits. First, the computation of the Technology Influence Scores and their visualization through the Technology Influence Maps offer a rapid and interactive means to review the information contained in the mappings. Second, it enables the quick identification of inaccurate/unexpected Technology Influence Scores, hence supporting the modification of the mappings, and facilitating the creation of the Cross Influence Matrices. As such Cross Impact Analysis, through the computation and visualization of Technology Influence Scores, represents a first and necessary step in the definition of technology relationships.

Hypothesis Verification

The implementation of Cross Impact Analysis to this problem has shown to only provide partial information regarding technology relationships: we can only differentiate between technology pairs having no influence on one another and technology pairs having some kind of influence. In particular, Cross Impact Analysis has failed to fully capture the integration of stand-alone technologies (no differentiation between synergistic and mutually exclusive technologies) and to faithfully represent the complexity of their relationships. Consequently, **Hypothesis 1.2 is only partially verified.**

In the remainder of this work, Cross Influence Matrices are thus developed based on knowledge gained from the computations of Technology Influence Scores and further populated using information from the relevant literature. However, while defining the type of relationships between technologies is important, these relationships, to be of any practical interest, need to be translated into performance indicators and quantitatively evaluated at the airport level. The following section discusses the determination of combined technologies impact factors, as well as the evaluation of technology portfolios' impact on metrics.

5.2 Step 2b: Determination of Combined Technologies Impact Factors

The following section discusses the definition of the impact rules that provide the basis for the determination of combined technology impact factors for any given metric.

5.2.1 Definition of Impact Rules

As previously discussed, impact rules enable the computation of the k-factors necessary to translate technical impacts into system level impacts. In particular, the definition of impact rules is based on the assumption that the combined technical impact of two technologies depends on how related those technologies are. In other words, the impact of a combined set of technologies on a **given metric** is based on the nature of the technology relationships defined in the Cross Influence Matrices discussed in Step 5.1.1. Consequently, for the present problem, impact rules can be defined with respect to the four following scenarios, as illustrated in Figure 67.

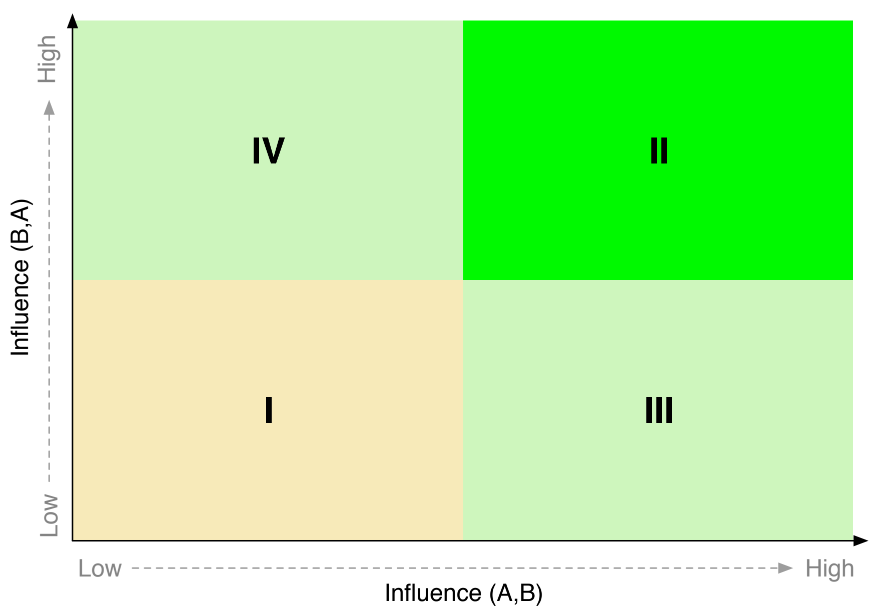


Figure 67: Definition of impact rules.

- **Scenario I:** In this scenario, both $Influence(A, B)$ and $Influence(B, A)$ are low, meaning that Technologies A and B have no influence on one another (Figure 57). In this scenario, the combined impact of these two technologies is defined by Equation 7 as:

$$k_{AB} = k_A + k_B \tag{7}$$

- **Scenario II:** In this scenario, both $Influence(A, B)$ and $Influence(B, A)$ are high, indicative of a synergistic relationship between the two technologies. In other words, Technologies A and B can collaborate and complement each other to the point that they can be assimilated to a single Technology C. In this instance, the combined impact of these two technologies is defined by Equation 8 as:

$$k_{AB} = k_C = \alpha_{AB} * (k_A + k_B) \tag{8}$$

  where α is a parameter set by the equipment provider for each synergistic relationship and corresponding metric

- **Scenario III:** In this scenario $Influence(A, B)$ is high and $Influence(B, A)$ is low, meaning that the presence of Technology A implies the presence of Technology B (Figure 57). In other words, if technology B is already present then one can decide to later invest in Technology A. In such a scenario, the combined impact of these two technologies is defined by 9 as:

$$k_{AB} = k_A \tag{9}$$

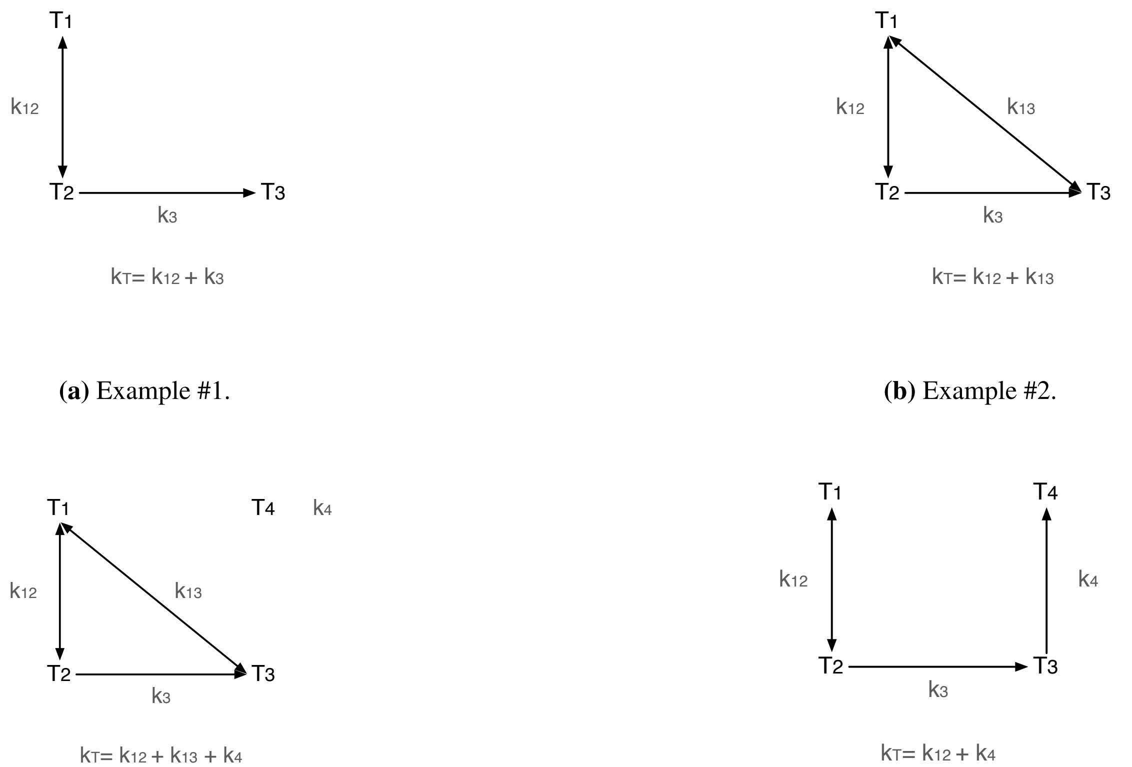
- **Scenario IV:** In this scenario $Influence(A, B)$ is low and $Influence(B, A)$ is high, meaning that the presence of Technology B implies the presence of Technology A (Figure 57). In other words, if technology A is already present then one can decide to later invest in Technology B. In this scenario, the combined impact of these two technologies is thus defined by Equation 10 as:

$$k_{AB} = k_B \tag{10}$$

The k-factors (k_A, k_B, etc.) and α's are parameters that can be defined by the equipment provider, experts, or from a thorough review of relevant field studies. In addition, it is important to note that, although two technologies may support the same function, they do not necessarily influence one another. Hence, functional influence does not imply technological influence. Finally, the impact rules defined above are provided for pairs of technologies having some influence on the same metric.

The assessment of the impact of a technology portfolio including more than two technologies is more difficult, due to the multitude of possible technology combinations. The following section provides examples of technology combinations and discuss the determination of their overall impact factor. Then a generic approach, based on the rules defined in Section 5.2.1 is proposed to automatically compute the impact factor of any technology combination on a given metric.

5.2.2 Examples



(a) Example #1.

(b) Example #2.

(c) Example #3.

(d) Example #4.

Figure 68: Examples of technology portfolios and their Impact.

In Example #1 (Figure 68(a)):

- Technologies 1 and 2 are synergistic: the resulting impact is k_{12} (Equation 7)
- Technologies 2 and 3 have a unilateral influence, where the presence of Technology 3 implies the presence of Technology 2: the resulting impact is k_3 (Equation 10)

The total impact of this technology portfolio is thus the sum of k_{12} and k_3: $k_T = k_{12} + k_3$

In Example #2 (Figure 68(b)):

- Technologies 1 and 2 are synergistic: the resulting impact is k_{12} (Equation 7)

- Technologies 1 and 3 are synergistic: the resulting impact is k_{13} (Equation 7)

- Technologies 2 and 3 have a unilateral influence, where the presence of Technology 3 implies the presence of Technology 2: the resulting impact is k_3 (Equation 10)

When in the presence of both synergistic and unilateral relationships, if one technology belongs to both relationships (Technology 3 in this case), then its single impact (k_3) is disregarded. It is thus assumed that only the biggest impact between a synergistic and a unilateral relationship is considered. In this example, because $k_3 < k_{13} = \alpha_{13} * (k_1 + k_3)$ and is thus already accounted for in k_{13}, the impact due to the unilateral influence between Technologies 2 and 3 is disregarded. The total impact of this technology portfolio is thus the sum of k_{12} and k_{13} only: $k_T = k_{12} + k_{13}$

In Example #3 (Figure 68(c)):

- Technologies 1 and 2 are synergistic: the resulting impact is k_{12} (Equation 7)

- Technologies 1 and 3 are synergistic: the resulting impact is k_{13} (Equation 7)

- Technologies 2 and 3 have a unilateral influence, where the presence of Technology 3 implies the presence of Technology 2: the resulting impact is k_3 (Equation 10)

- Technology 4 has no influence on any other technologies present in that portfolio: the resulting impact is k_1+k_2+k_3+k_4 (Equation 9)

However, $k_1 < k_{12} = \alpha_{12} * (k_1 + k_2)$, $k_2 < k_{12} = \alpha_{12} * (k_1 + k_2)$ and $k_3 < k_{13} = \alpha_{13} * (k_1 + k_3)$. Hence, based on the aforementioned assumption, the impacts k_1, k_2, k_3 are disregarded. The total impact of this technology portfolio is thus the sum of k_{12}, k_{13} and k_4: $k_T = k_{12} + k_{13} + k_4$

In Example #4 (Figure 68(d)):

- Technologies 1 and 2 are synergistic: the resulting impact is k_{12} (Equation 7)

- Technologies 2 and 3 have a unilateral influence, where the presence of Technology 3 implies the presence of Technology 2: the resulting impact is k_3 (Equation 10)
- Technologies 3 and 4 have a unilateral influence, where the presence of Technology 4 implies the presence of Technology 3: the resulting impact is k_4 (Equation 10)

Because the unilateral influences of Technologies 2, 3 and 4 are equivalent to a unilateral influence between Technologies 2 and 4 only (the presence of Technology 4 assuming the presence of Technology 2, with a resulting impact k_4), the total impact of this technology portfolio is thus the sum of k_{12} and k_4: $k_T = k_{12} + k_4$

5.2.3 Generalization

Based on these examples, a more general formulation can be proposed. This formulation is obtained by first representing the relationships of any pairs of technologies in matrix form using 0's and 1's. Hence:

- If the presence of Technology i has no influence on the presence of Technology j, then $m_{ij} = 0$. Similarly if the presence of Technology j has no influence on the presence of Technology i, then $m_{ji} = 0$
- If the presence of Technology i implies the presence of Technology j, then $m_{ij} = 1$. Similarly, if the presence of Technology j implies the presence of Technology i, then $m_{ji} = 1$

Consequently, the three types of technology relationships (synergistic, unilateral influence, no influence) can be represented as follows:

- Technologies i and j are synergistic: $m_{ij} = m_{ji} = 1$
- Technologies i and j have no influence on one another: $m_{ij} = m_{ji} = 0$

- Technologies i and j have a unilateral influence: $(m_{ij}, m_{ji}) = (0,1)$ or $(1,0)$, depending on which technology implies the presence of the other

This formulation is illustrated in Tables 23 and 24, where a Cross Influence Matrix is mapped to a Binary Matrix.

		Technology B				
		T_{13}	T_{14}	T_{15}	T_{16}	T_{17}
Technology A	T_{13}					
	T_{14}					
	T_{15}					
	T_{16}					
	T_{17}					

Table 23: Cross Influence Matrix

		Technology j				
		T_{13}	T_{14}	T_{15}	T_{16}	T_{17}
Technology i	T_{13}		1	0	0	0
	T_{14}	0		0	0	0
	T_{15}	0	0		0	1
	T_{16}	0	0	0		0
	T_{17}	0	0	1	0	

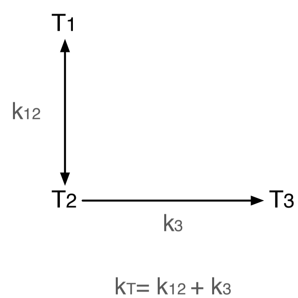
Table 24: Binary matrix

The binary matrices for each of the examples discussed above are provided in Figure 69. Using this formulation, the impact factor of combined technologies can be computed for any given metric by checking the relationship between technologies, as discussed below. The assumptions of the proposed algorithm are as follows:

- **Assumption #1:** If one technology belongs to both a synergistic and unilateral relationship, then only the biggest impact between these two relationships is considered, i.e the impact from the unilateral relationship is disregarded

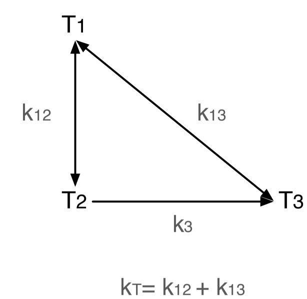
- **Assumption #2:** If the presence of T_k implies the presence of T_j, which in turns implies the presence of T_i, etc., the resulting combined impact is T_k

- **Assumption #3:** If the presence of a technology T_k implies the presence of two technologies T_i and T_j then the combined impact T_k is only accounted once



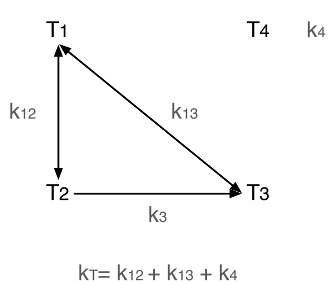
Tech. i \ Tech. j	T_1	T_2	T_3
T_1		1	0
T_2	1		0
T_3	0	1	

(a) Example #1.



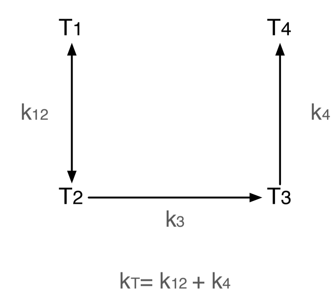
Tech. i \ Tech. j	T_1	T_2	T_3
T_1		1	1
T_2	1		0
T_3	1	1	

(b) Example #2.



Tech. i \ Tech. j	T_1	T_2	T_3	T_4
T_1		1	1	0
T_2	1		0	0
T_3	1	1		0
T_4	0	0	0	

(c) Example #3.

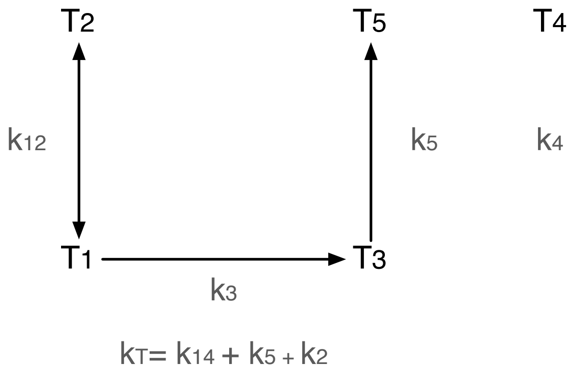


Tech. i \ Tech. j	T_1	T_2	T_3	T_4
T_1		1	0	0
T_2	1		0	0
T_3	0	1		0
T_4	0	0	1	

(d) Example #4.

Figure 69: Examples of technology portfolios and their corresponding binary matrices.

This algorithm is further discussed in the context of the following example (Figure 70).



	Tech. j				
Tech. i	T_1	T_2	T_3	T_4	T_5
T_1		1	0	0	0
T_2	1		0	0	0
T_3	1	0		0	0
T_4	0	0	0		0
T_5	0	0	1	0	

Figure 70: Example of a technology portfolio and its binary matrix.

In particular, the three types of technology relationships and their respective impacts are identified through the following structure:

- **Test for synergistic influence:** As discussed in Section 5.2.3, two technologies T_i and T_j are synergistic if $m_{ij} = m_{ji} = 1$ (Figure 71). Their impact is then $k_{ij} = \alpha_{ij} * (k_i + k_j)$ (Equation 7).

	Tech. j				
Tech. i	T_1	T_2	T_3	T_4	T_5
T_1		1	0	0	0
T_2	1		0	0	0
T_3	1	0		0	0
T_4	0	0	0		0
T_5	0	0	1	0	

Figure 71: Technologies having a synergistic influence.

- **Test for unilateral influence:** A unilateral relationship can be from Technology i to Technology j or vice versa, as illustrated in Figure 72. Consequently, both situations need to be tested to decide if the impact of the technologies combined is either k_i or k_j.

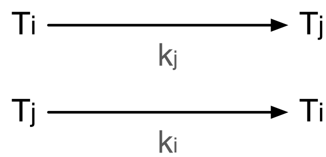


Figure 72: Technologies having a unilateral influence.

Also, as illustrated in Example #5 (Figure 70), the algorithm needs to account for unilateral relationships that involve more than two technologies. In particular, it needs to distinguish between technologies only involved in unilateral relationships as opposed to technologies being involved in both synergistic and unilateral relationships (as is T_j in the following example). This is done to ensure that, if the scenario illustrated in Figure 73 occurs, then only the biggest impact between a synergistic and a unilateral relationship is accounted for (according to the assumptions aforementioned, k_j is discarded and only $k_{jk} = \alpha_{jk} * (k_j + k_k)$ remains)

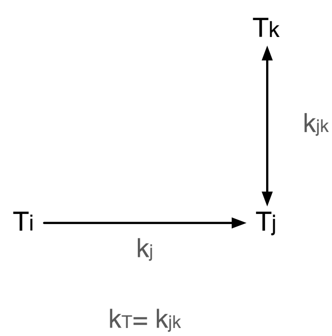


Figure 73: Technology involved in both unilateral and synergistic relationships.

In addition, the test for unilateral influence should ensure that consecutive unilateral relationships are captured and that the overall impact of the technologies involved in these relationships (T_1, T_3 and T_5 in the case of Example #5) is computed accordingly. When examining the unilateral relationship between T_1 and T_3 in Example #5, where the presence of T_3 implies the presence of T_1, the algorithm also checks if the presence of any other technology(ies) implies the presence of T_3. If such is the case, then there is a term m_{k3} (with $k \in$ {set of technologies}) equal to 1 in the corresponding binary matrix and the impact resulting from the $T_1 - T_3$ relationship is not accounted for. On the other hand, if there is no such term, then the combined impact is k_3. In Example #5, the presence of T_5 implies the presence of T_3, as illustrated by the term $m_{53} = 1$ in Figure 74. However, there is no term for which m_{k5} (with $k \in$ {set of technologies}) is equal to 1. Consequently, the impact of the relationship between technologies T_3 and T_5 is accounted for and is equivalent to k_5.

		Tech. j				
		T_1	T_2	T_3	T_4	T_5
Tech. i	T_1		1	0	0	0
	T_2	1		0	0	0
	T_3	1	0		0	0
	T_4	0	0	0		0
	T_5	0	0	1	0	

Figure 74: Technologies having a unilateral influence.

Finally, in the case where the presence of a technology T_k implies the presence of two technologies T_i and T_j, as illustrated in Figure 75, then the algorithm ensures that the impact of T_k is only accounted once.

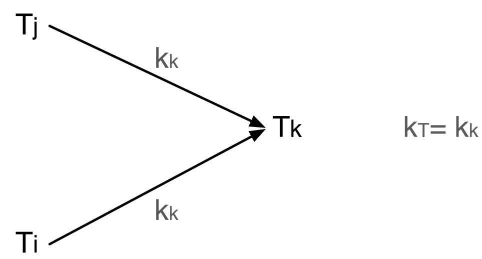


Figure 75: Technology requiring the presence of two technologies.

- **Test for no influence:** A Technology j has no influence on any other technologies if:

$$m_{jk} = m_{kj} = 0 \text{ for all } k \in \{\text{set of technologies}\} \text{ (Figure 76)} \tag{11}$$

or, in other words, if:

$$\sum_{k=1}^{k=NbTech} m_{jk} + \sum_{k=1}^{k=NbTech} m_{kj} = 0 \tag{12}$$

and, its impact is equivalent to k_j

		Tech. j				
		T_1	T_2	T_3	T_4	T_5
Tech. i	T_1		1	0	0	0
	T_2	1		0	0	0
	T_3	1	0		0	0
	T_4	0	0	0		0
	T_5	0	0	1	0	

Figure 76: Technology having no influence on any other technologies.

The proposed algorithm evaluates the relationship of T_j with other technologies as many times as there are technologies T_i for $i \neq j$ and $i \in$ {set of technologies}. In the Example #5, each examination of T_4 with any other technologies would result in an impact factor k_4 being added to the total impact factor k_T. Therefore, to prevent the impact of T_j from being accounted more than once, a counter n_j is incremented each time a relationship involving T_j is evaluated. Consequently, if this counter exceeds 1 then k_j is subtracted from k_T and n_j is reinitialized to 1.

5.2.4 Preliminary Remarks

The impact of any technology on a given metric can be obtained by reviewing the relevant literature (field studies, etc.) and/or by consulting subject matter experts. Eventually, the impact factors of each individual technology on the metrics of interest can be summarized in a Technology Impact Matrix, as illustrated in Table 25. An impact factor represents either a degradation or an improvement, and is used to model the changes introduced by technologies on the metrics. As illustrated in the table below, Technology T_0, for example, decreases the value of the metric M_1 by 10 percent.

Table 25: Example of a Technology Impact Matrix.

		Technical Metrics				
		M₁	**M₂**	**M₃**	.....	**M₄**
Technologies	**T₀**	-10%		-5%	-2%	
	T₁		-2%	-7%		
	T₂					-15%
	.....	.....	.....	.....	.....	.....
	T₃₅	-5%	-2%		-2%	

As discussed, assessing the impact of combined technologies is a more challenging endeavor that involves:

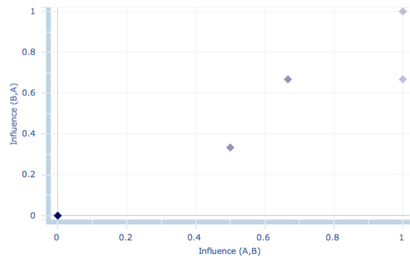
- Defining the causal impact and type of relationships between technology pairs: this is achieved by:
  - Studying the information provided by Cross Impact Analysis to verify and modify, if necessary, the mappings of technology pairs that do not exhibit the expected relationship

  - Leveraging that information to create Cross Influence Matrices for each function and each technology pair

- Generating the corresponding Binary Matrix

- Evaluating the impact factor of combined technologies on each metric using the proposed formulation along with the TIM previously defined

This process, which is further illustrated in Figure 77, leads to the definition and computation of technical impact factors for combined technologies. These impacts, to be of any practical interest and value, need to be further translated into airport performance indicators (e.g delay, capacity, etc.). The following chapter discusses the development of a modeling and simulation environment to quantitatively assess the impact of combined technologies at the airport level.



Technology Influence Map

	Technology B				
Technology A	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}
T_{13}					
T_{14}					
T_{15}					
T_{16}					
T_{17}					

Cross Influence Matrix

	Technology j				
Technology i	T_{13}	T_{14}	T_{15}	T_{16}	T_{17}
T_{13}		1	0	0	0
T_{14}	0		0	0	0
T_{15}	0	0		0	1
T_{16}	0	0	0		0
T_{17}	0	0	1	0	

Binary Matrix

+

	Technical Metrics				
Technologies	**M_1**	**M_2**	**M_3**	.....	**M_4**
T_0	-10%		-5%	-2%	
T_1		-2%	-7%		
T_2					-15%
.....	.....	.....	.....	.....	.....
T_{35}	-5%	-2%		-2%	

Technology Impact Matrix

Proposed Formulation

	Technical Metrics				
Technologies	**M_1**	**M_2**	**M_3**	.....	**M_4**
T_0	-10%		-5%	-2%	
T_1		-2%	-7%		
T_2					-15%
.....	.....	.....	.....	.....	.....
T_{35}	-5%	-2%		-2%	
Combined Impact	$-v\%$	$-w\%$	$-x\%$	$-y\%$	$-z\%$

Combined Technologies Impact Matrix

Figure 77: Process for the computation of technical impact metrics of combined technologies.

CHAPTER VI

STEP #3: CREATION OF THE MODELING & SIMULATION ENVIRONMENT

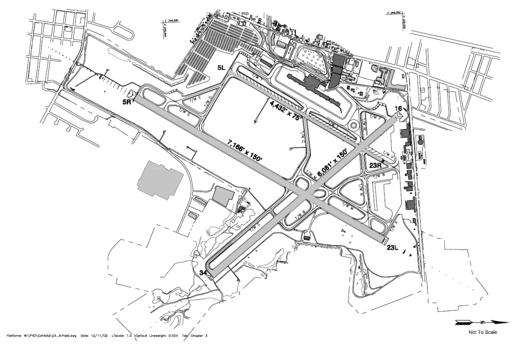
The modeling and simulation environment discussed in this chapter is articulated around two main components: an airport model (Section 6.1), that supports the translation of technology impact factors into airport performance indicators, and a System Dynamics model (Section 6.2) that helps identify the key factors that drive the need for capacity expansion. The overall architecture and logic behind this modeling and simulation environment is further presented in Section 6.3. Finally, Section 6.4 discusses the use of Systems Dynamics and sensitivity analysis as a means to address **Research Question 2: How can the need for capacity expansion and resulting technology investments be identified and characterized?**

6.1 Airport Modeling

Section 6.1.1 describes the airport chosen for this work. Section 6.1.2 provides a brief description of MACAD, its input and outputs, and further discusses the simplifications and assumptions made to model the airport's operations.

6.1.1 Airport Description

For the purpose of this work, an airport resembling Theodore Francis Green Airport (PVD) is modeled. T. F. Green Airport is classified in the National Plan of Integrated Airport Systems (NPIAS) as a medium commercial service airport and currently serves as a reliever airport for Logan International Airport.



(a) Layout of T. F. Green airport [197].

(b) Aerial view [1].

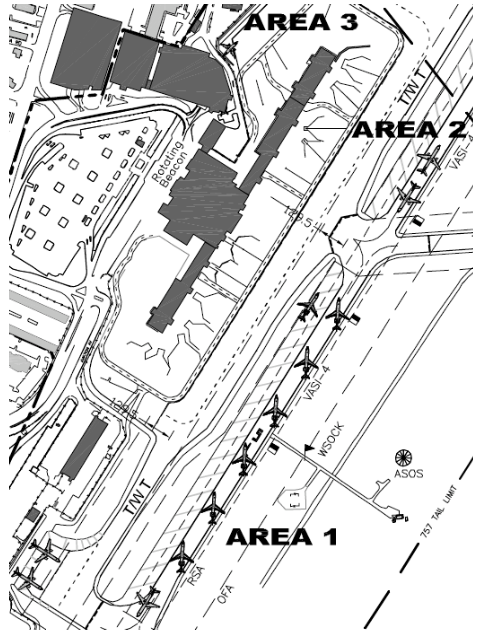
Figure 78: T. F. Green airport airfield.

The airfield (Figure 78) is composed of two parallel runways (5L/23R and 5R/23L) and one crosswind runway (16/34). Runway 5L/23R is used only by small GA aircraft during visual, daytime conditions. This runway accommodates one to two operations per hour and provides a 3% increase in overall capacity [197]. The crosswind runway (16/34) does not provide much additional capacity. Indeed, as discussed in the airport master plan, the capacity of the two runways (16/34 and 5R/23L) together is not significantly higher than the capacity provided by a single runway [197].

The apron[1] has a buffer capacity of 13 aircraft (Figure 79(b)). The airport also has 17 aviobridges (to accommodate small, medium and large aricraft) and 6 remote stands (to accommodate small aircraft only) (Figure 79(a)).

[1]"The paved area in front of an aircraft hangar where aircraft can be parked and tied down. Aprons are sometimes called ramps or tarmacs" [20]

(a) T. F. Green airport terminal area [197].



(b) Apron buffer capacity [197].

Figure 79: T. F. Green airport airside.

The following section discusses the use of MACAD as a means to model the airport described above.

6.1.2 The Master Airfield CApacity and Delay (MACAD) Model

The Master Airfield CApacity and Delay (MACAD) Model, provided to the author by Professor Zografos from the Athens University of Economics and Business, consists of the integration of three different macroscopic models (a runway capacity model, a runway delay model, an apron/taxiway model) aimed at estimating the capacity and delays at an airport under various scenarios [278]. As discussed in [279], "the models account for the dynamic characteristics of airfield capacity and demand, as well as for some stochastic aspects of airfield operations. They are sensitive to airfield geometry, the operational characteristics of the airfield and of the local air traffic control system, and the characteristics of the local air traffic demand for airport access and services." MACAD has been previously implemented to study and analyze the implications on level of service of changes in demand or increase in capacity due to new infrastructure [278]. Also, it has recently been integrated within a decision support system (SPADE DSS) to support the management and planning of total airport operations [343]. More importantly, the accuracy of its results has been judged satisfying for airport strategic decision making purposes [278]. A more detailed descriptions of MACAD's capabilities and its applicability to this problem can found in Chapter 2 Section 2.6.

6.1.2.1 Model Inputs and Outputs

The inputs required by MACAD to provide estimates of capacity and delay at an airport can be categorized in terms of:

- Runway properties: runway set type, configuration, occupancy times, etc.
- Aircraft properties: aircraft types, aircraft separations, etc.
- Schedule properties: type of aircraft arriving at each hour of the day, etc.
- Airline and handler properties: number of airlines and handlers
- Gate properties: apron attributes, turn around times, number of stands, etc.

The inputs selected for this research, along with the different responses of interest, are summarized in Figure 80. These were chosen based on 1) their ability to represent the traffic at the airport, 2) their potential for capturing the impact that technologies may have on airport operations. The remaining inputs available from MACAD are thus considered fixed (constant).

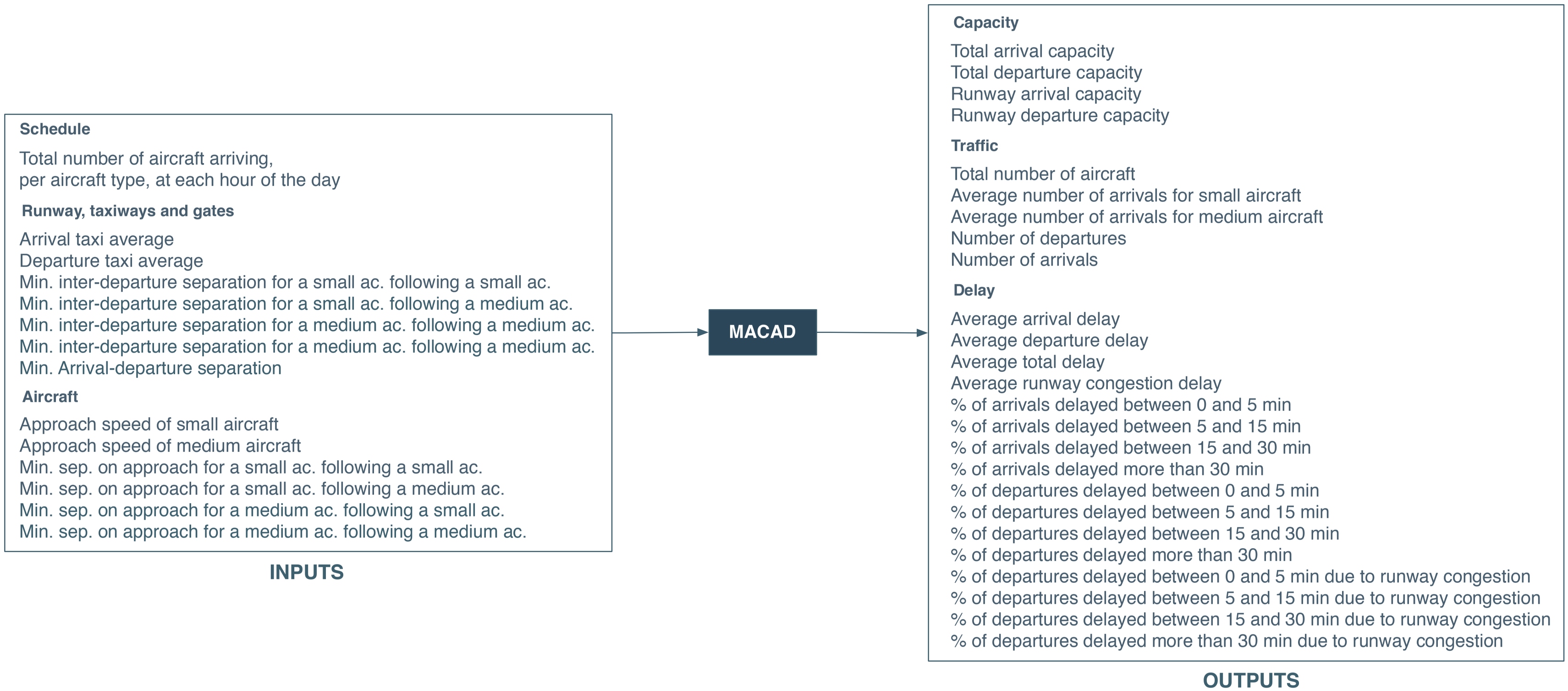


Figure 80: MACAD inputs and outputs considered.

6.1.2.2 Aircraft Schedule and Traffic Mix

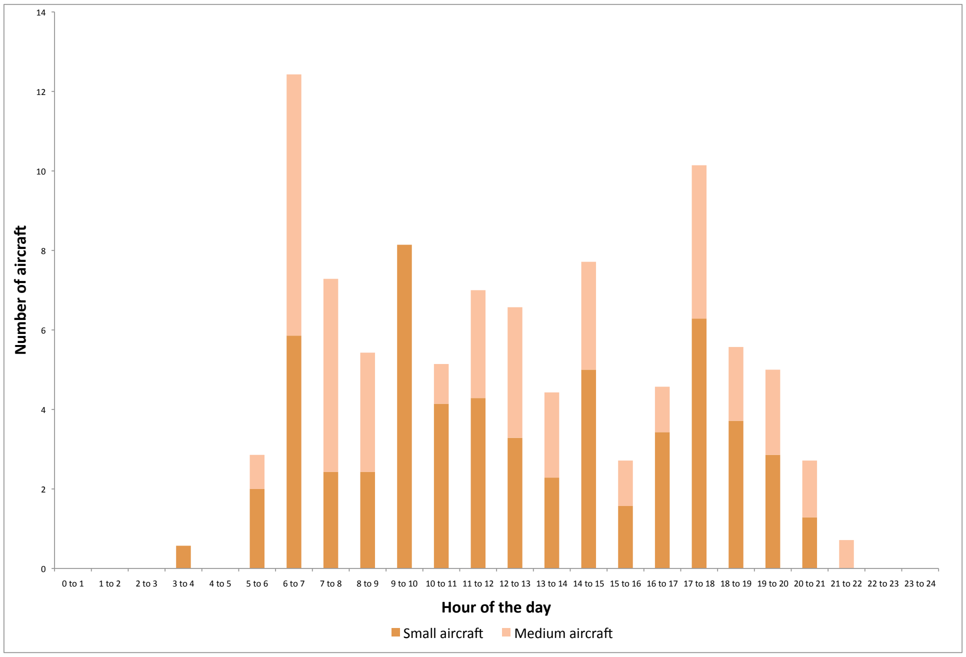
The airport's traffic is modeled based on traffic data collected from July 10^{th}, 2011 to July 16^{th}, 2011. In particular, the number of arriving aircraft can be modeled in MACAD through an aggregate schedule. This schedule specifies the number and type of arriving aircraft for each hour of the day, as well as the average and standard deviation of the time aircraft are scheduled to depart after arrival. Hence, as explained in [278], arrival flights are assumed to be randomly distributed within each hour. MACAD then generates a scheduled departure time for each flight using a pseudo random number generator and the statistics provided. As such, the same arrival flight schedule can result in a somewhat different departure schedule. Additional information and detail regarding the architecture and logic behind MACAD can be found in [278].

MACAD defines aircraft types as summarized in Table 26. A review of the types of aircraft currently operating at PVD leads to consider only "small" and "medium" aircraft in this modeling effort.

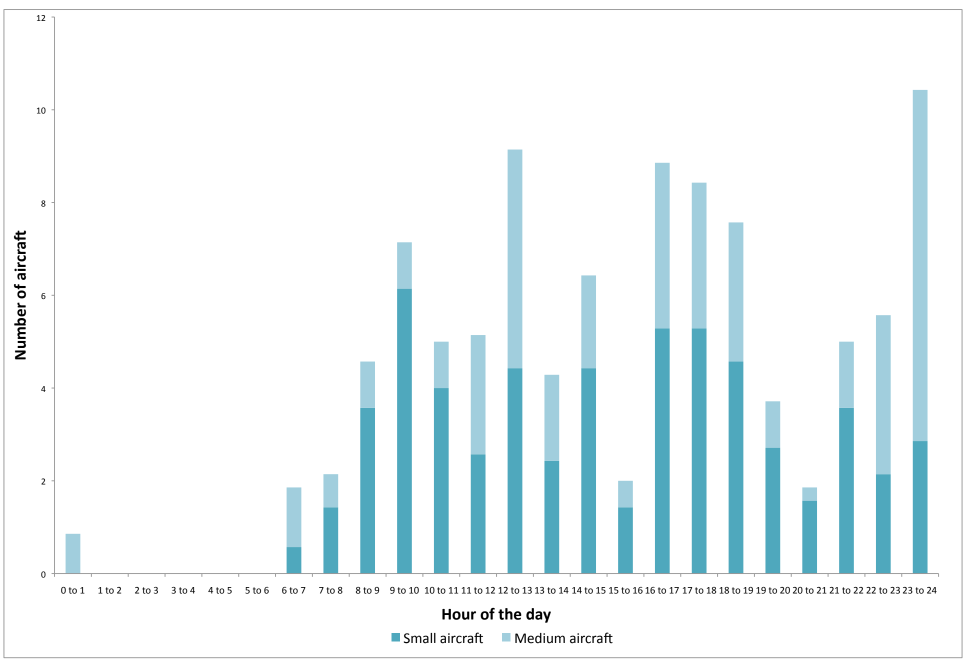
Table 26: MACAD Aircraft Types

Aircraft Types	Description
Small	All models not included in other categories
Medium	B727, B737, A320, DC9, and MD90
Large	B757, B767, A300, and A310
Wide	DC10, MD11 and L1011
Jumbo	B747, B777, A340, and A330

This categorization is thus used to compute the average number of departing and arriving flights per aircraft category for each hour of the day. These average number of flights, illustrated in Figures 81(a) and 81(b), are based on traffic at the airport for the week considered.



(a) Average number of departing flights for each aircraft category.



(b) Average number of arriving flights for each aircraft category.

Figure 81: Hourly-based average number of departing and arriving flights for each aircraft category

As previously discussed, MACAD requires the user to provide the number and type of aircraft arriving at each hour of the day. Consequently, given the two types of aircraft considered (small and medium), a schedule, to be properly defined, requires 48 variables. In order to maintain a manageable number of variables and a level of detail, the following simplifications and assumptions are proposed:

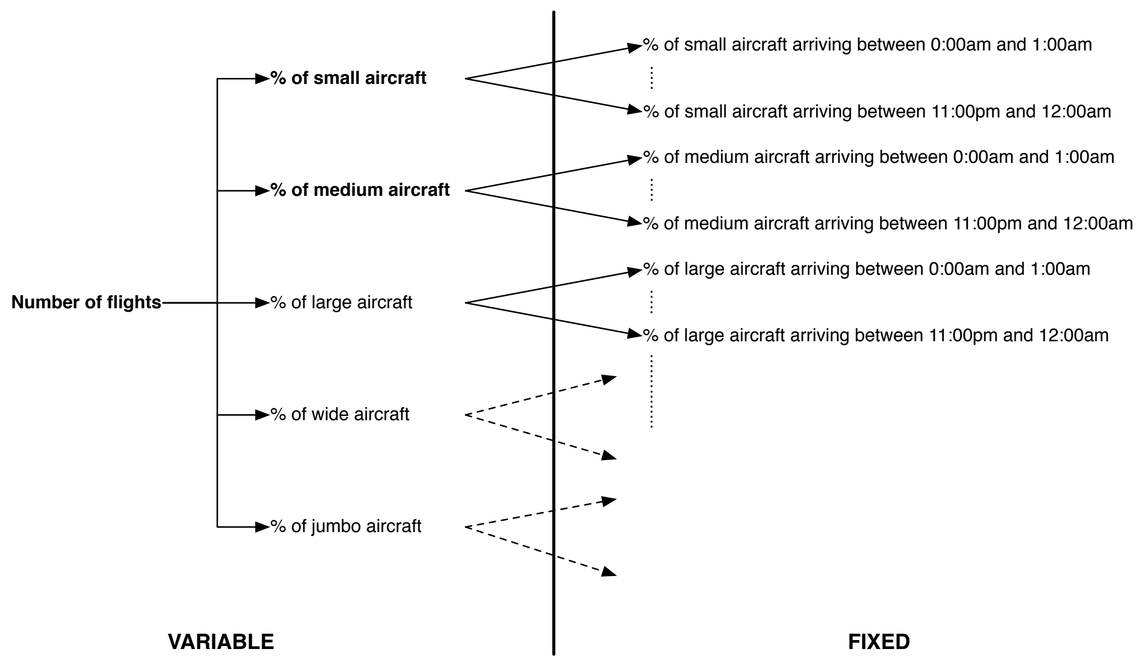


Figure 82: Simplification and assumptions made to the definition of aircraft schedules.

- The number of arrivals for each type of aircraft at each hour of the day is obtained from the total number of aircraft per day and the percentage of each type of aircraft arriving to the airport at each hour (Figure 82)
- These percentages, provided in Table 27, are averages based on traffic data collected from July 10^{th}, 2011 to July 16^{th}, 2011. These are considered fixed. In other words, the airport is seeing the same traffic pattern each day (i.e. peak hours remain the same, independently of the level of traffic experienced at the airport)

Consequently, in the scenario of an increase in demand, the airlines response can be modeled by either increasing the number of aircraft (equivalent to an increase in flight

Table 27: Percentage and type of arriving and departing aircraft for each hour of the day based on traffic data collected from July 10^{th}, 2011 to July 16^{th}, 2011

Hour of the day	**Small Aircraft (%)**		**Medium Aircraft (%)**	
	Arriving (%)	**Departing (%)**	**Arriving (%)**	**Departing (%)**
0:00am $\leqslant h <$ 1:00am	0.00	0.00	2.07	0.00
1:00am $\leqslant h <$ 2:00am	0.00	0.00	0.00	0.00
2:00am $\leqslant h <$ 3:00am	0.00	0.00	0.00	0.00
3:00am $\leqslant h <$ 4:00am	0.00	0.91	0.00	0.00
4:00am $\leqslant h <$ 5:00am	0.00	0.00	0.00	0.00
5:00am $\leqslant h <$ 6:00am	0.00	3.40	0.00	2.21
6:00am $\leqslant h <$ 7:00am	0.93	9.66	3.00	16.67
7:00am $\leqslant h <$ 8:00am	2.42	4.02	1.64	12.40
8:00am $\leqslant h <$ 9:00am	5.85	4.02	2.51	7.77
9:00am $\leqslant h <$ 10:00am	10.24	13.65	2.49	0.00
10:00am $\leqslant h <$ 11:00am	6.83	6.90	2.49	2.56
11:00am $\leqslant h <$ 12:00pm	4.51	7.41	6.21	6.84
12:00pm $\leqslant h <$ 1:00pm	7.56	5.67	11.37	8.12
1:00pm $\leqslant h <$ 2:00pm	4.27	3.91	4.56	5.56
2:00pm $\leqslant h <$ 3:00pm	7.50	8.51	4.99	6.82
3:00pm $\leqslant h <$ 4:00pm	2.32	2.63	1.49	3.00
4:00pm $\leqslant h <$ 5:00pm	9.07	5.63	8.68	3.00
5:00pm $\leqslant h <$ 6:00pm	9.04	10.68	7.48	9.82
6:00pm $\leqslant h <$ 7:00pm	7.68	6.20	7.36	4.69
7:00pm $\leqslant h <$ 8:00pm	4.57	4.69	2.49	5.34
8:00pm $\leqslant h <$ 9:00pm	2.71	2.12	0.76	3.49
9:00pm $\leqslant h <$ 10:00pm	5.94	0.00	3.79	1.71
10:00pm $\leqslant h <$ 11:00pm	3.71	0.00	8.32	0.00
11:00pm $\leqslant h <$ 12:00am	4.84	0.00	18.65	0.00

frequencies) and/or modifying the traffic mix (equivalent to operating more or fewer small aircraft). The option of schedule smoothing or off peak flying is not considered in this work.

6.1.2.3 Runway Configuration and Modeling

From the runway operating configurations provided in Figure 83, it appears that runway 5R/23L is used for 87.08% of arrival and departure operations. Therefore, for simplification purposes, only runway 5R/23L is modeled.

6.1.2.4 Baseline Definition and Model Calibration

A baseline is defined to help compare airport operations under different scenarios. The objective of this baseline is thus to provide a realistic representation of the airport under its current operating conditions. It is based on traffic data collected from July 10^{th}, 2011 to July 16^{th}, 2011, as well as data and information gathered from the airport's master plan [197]. During that week, the airport accommodated on average 99 departures and 100 arrivals per day. The traffic is composed of about 60% small aircraft and 40% medium aircraft (mainly Southwest airlines operations).

Because MACAD uses a daily schedule to model operations, aircraft that arrive late in the evening and remain at the airport for the night are not accounted for in the tally of next day departures. This is an issue in the case of T. F. Green Airport as a significant number of aircraft arrive after 10:00pm (mainly B733s from Southwest). These flights are thus not carried over and properly represented in the next day operations. To alleviate this issue and ensure that the number of departing aircraft represents the current level of traffic at the airport, the late evening arrivals for both small and medium aircraft are pushed to early morning arrivals. Hence, flights that arrive between 9:00pm and 12:00am in reality are modeled in MACAD as arriving between 12:00am and 3:00am. The turn around times for these flights are also defined so as to represent current conditions and obtain a departure traffic that mimics the one of the airport. While this shift in the number of operations has

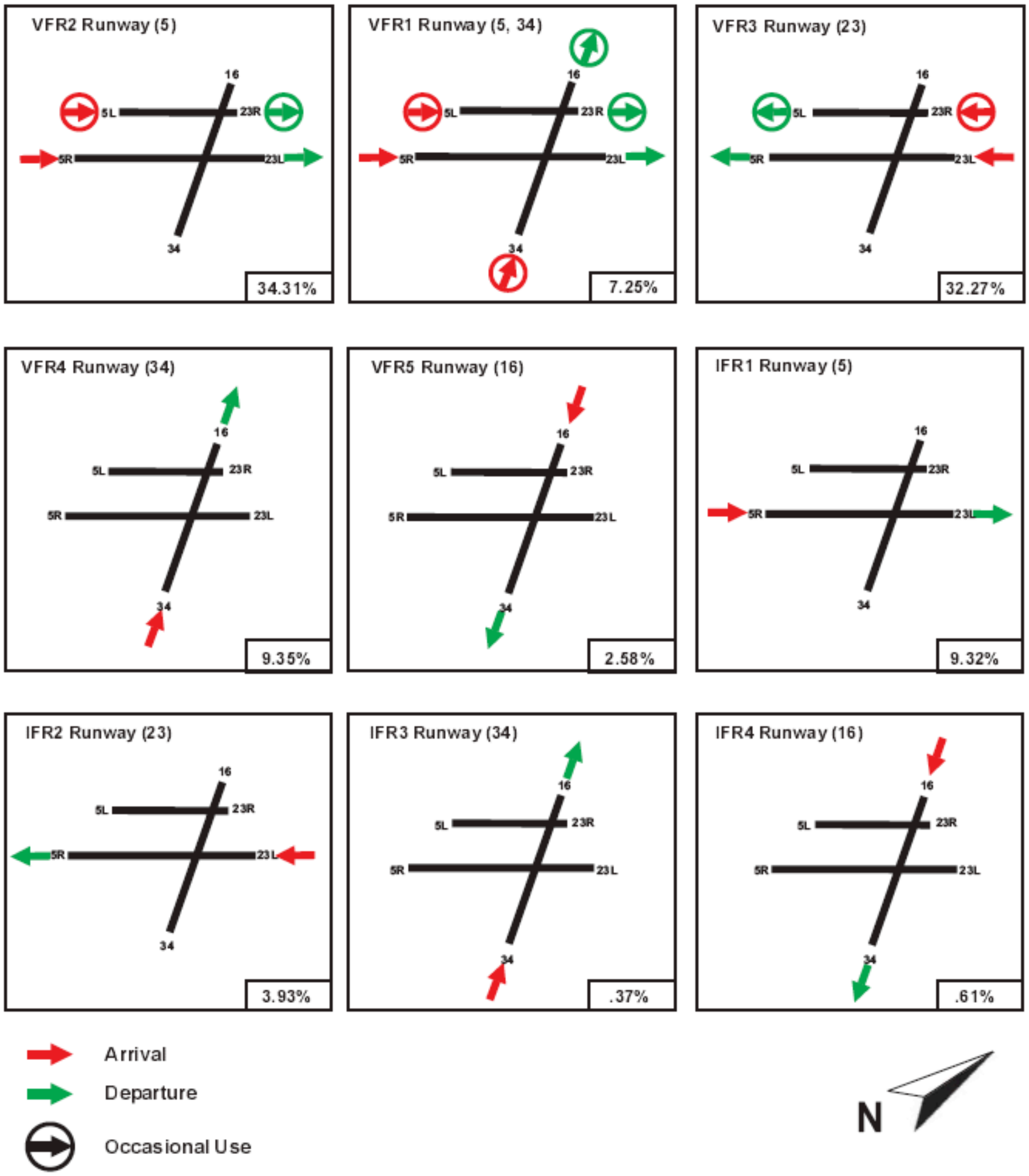


Figure 83: T. F. Green airport runway operating configurations [197].

an impact on when the resulting delays occur during the day (early morning as opposed to late evening), it does not have an impact of the total amount of delays experienced daily by aircraft.

Then, it is important to acknowledge that the delays estimated by the model, while within realistic bounds, cannot be used to appraise the ability of this baseline to faithfully represent the current traffic and conditions at PVD. Indeed, delays can occur for many reasons that are often out of the airport's control (weather, ground delay at an other airport, airlines tactical decisions, maintenance issues, late crew, etc.) and thus cannot be replicated using MACAD [278]. Hence, comparing delays generated by MACAD against actual delays at the airport does not provide any meaningful conclusions as to the goodness of the proposed baseline in representing the airport's current operating conditions.

Finally, due to the stochastic nature of airport operations and traffic demand, it is important that MACAD be run multiple times. Figure 84 illustrates the average of the average total delays (min per aircraft) for year 1 to 15, over 10 50, 100, 500, 1000, 1500 and 2000 repetitions. In particular, it shows that the variation in the average value of the response of interest is much less after 500 repetitions. Consequently, output values from MACAD will be obtained by running MACAD 500 times (which represents about 4 hours of running time) and taking the average of their respective values over these 500 runs.

As previously discussed, the airport model just described allows to translate technology impact factors into airport performance indicators. This information is then further integrated within the System Dynamics model described below to support the identification of the key factors (among the ones it includes) that drive the need for capacity expansion.

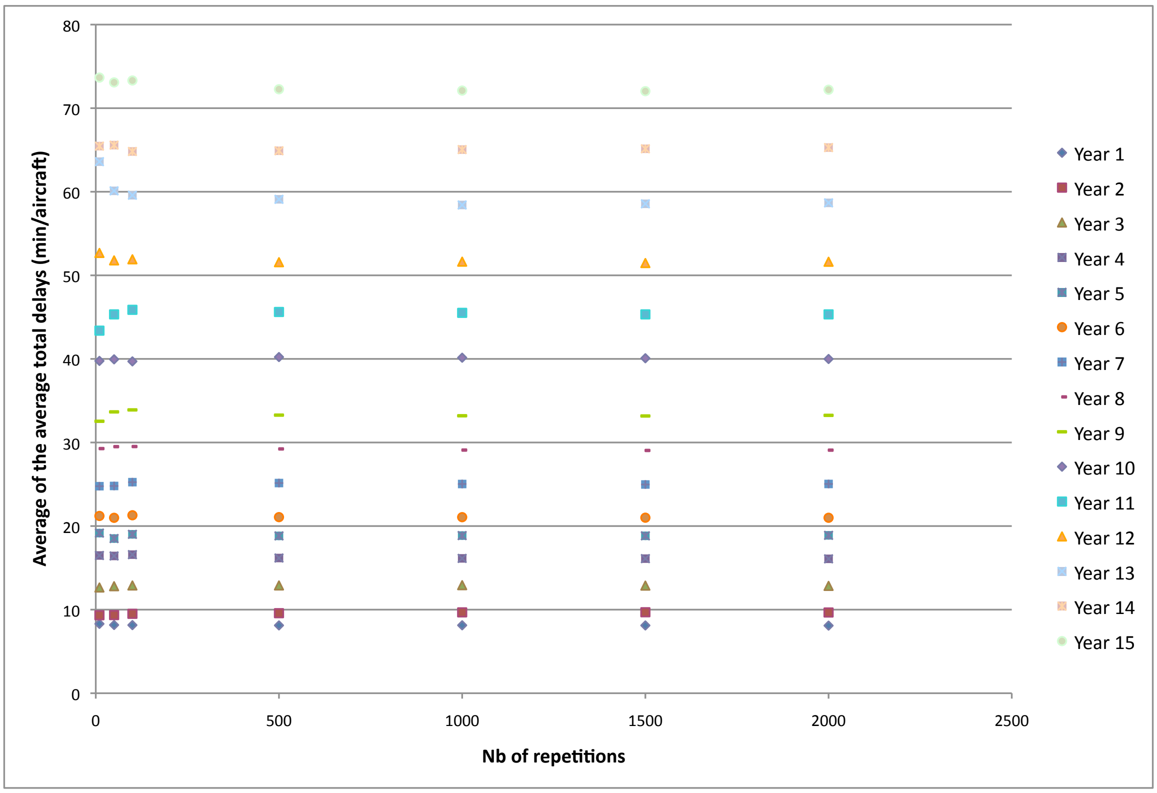


Figure 84: Average of the average total delays (min per aircraft) for year 1 to 15, over 10 50, 100, 500, 1000, 1500 and 2000 repetitions.

6.2 System Dynamics Modeling

As extensively discussed in Chapter 2, defining suitable investment strategies require that the dynamic structure and systemic complexity of the airport system be considered and understood. In particular, there is a need to study how airports respond to factors of change in order to eventually be able to identify and characterize the circumstances that drive the need for airport expansion.

Section 6.2.1 discusses the rationale for the variables included in the model. Section 6.2.2 further specifies the structure and logic of the System Dynamics model. Finally Section 6.2.3 details the behavioral relationships and assumptions made for each of the variables considered.

6.2.1 Key variables

The variables used in this System Dynamic modeling effort were down-selected following a thorough and extensive review of previous studies that used System Dynamics to address questions and challenges pertaining to the air transportation industry (see Section 2.8.1.1). In particular, the variables describing each System Dynamic model were compiled and used as a basis to create the following categorization (Figure 85). The compiled lists of variables from previous system dynamics models, along with the study(ies) they originate from, can be found in Appendix D.1.

Given the scope and focus on this research, the following categories are considered (in bold on Figure 85): operational (airside), societal (demand, economy), financial (airport), and technological. The complete sets of variables selected to be included in this modeling effort are summarized in Tables D.1 to D.5 and further discussed in Section 6.2.3. Additional variables or indicators of airport performance discussed in the *Resource Guide to Airport Performance Indicators* report [149] were also included in the list when relevant. In particular, metrics relevant to technology performance (Table 29) were added to the ones considered in previous studies. While the number of variables selected may seem limited,

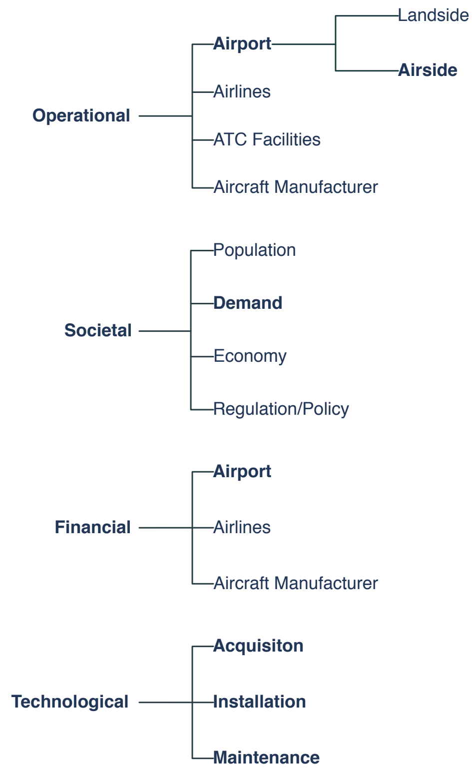


Figure 85: Categorization of variables used in previous System Dynamics modeling efforts.

this selection is based on the variables' relevance to the questions this work is trying to answer. It also reflects the author's desire to appropriately capture the interactions between each variable as opposed to building a model that would be too complex or detailed.

Table 28: Categories and descriptions of the metrics selected

Categories	Metrics
Airport Operations	Number of departures
	Number of arrivals
	Average total delay per aircraft
	Airside utilization ratio
	Runway utilization ratio
	Airside departure utilization ratio
	Airside arrival utilization ratio
	Runway departure utilization ratio
	Runway arrival utilization ratio
	Total departure capacity
	Total arrival capacity
	Total airside capacity
	Total runway capacity
	Runway departure capacity
	Runway arrival capacity
	Congestion
	Congestion threshold
	Number of peak hours
Demand	Number of aircraft arriving per day
	Percentage of small aircraft
Airport Finances	Airport revenues
	Loss of revenues due to congestion (penalty)
	Landing fees
	Maintenance costs
	Training costs
	Delivery costs
	Installation costs
	Technology costs

Table 29: Categories and descriptions of the metrics selected (continued)

Categories	Metrics
Airport Technologies	Approach speed of small aircraft
	Approach speed of medium aircraft
	Arrival runway occupancy time for small aircraft
	Arrival runway occupancy time for medium aircraft
	Departure runway occupancy time for small aircraft
	Departure runway occupancy time for medium aircraft
	Arrival taxi average
	Departure taxi average
	Min. separation on approach between two small aircraft
	Min. separation on approach between small and medium aircraft
	Min. separation on approach between medium and small aircraft
	Min. separation on approach between two medium aircraft
	Min. inter-departure separation between two small aircraft
	Min. inter-departure separation between small and medium aircraft
	Min. inter-departure separation between medium and small aircraft
	Min. inter-departure separation between two medium aircraft
	Min. separation between arriving and departing aircraft

6.2.2 Specification of structure

Figure 86 illustrates the structure of the System Dynamics model under consideration. The annual demand growth rate experienced at the airport is translated into an increase in the average number of flights per day, and/or into a change in the mix of aircraft operating at the airport. The increase in the average number of flights in turn generates more revenues through landing fees. However, it also results in increased delays and congestion. When congestion reaches a given threshold, the airport is penalized by losing revenues. This loss in revenues is used, in this model, as an incentive for the airport to address the congestion issue. The decrease in resource adequacy can be remedied by deploying additional ground technologies. These technologies, by adding capacity and reducing delays, allow more aircraft to operate at lower congestions levels. This in tun translates into increased revenues for the airport. However, these technologies also come at a cost to the airport (maintenance, training, installation, and delivery costs). Eventually, as described in Chapter 7, this model will be used to evaluate the ability of various technology portfolios to address airport expansion needs. This assessment will be carried out using the revenue, cost and airport performance information generated by this modeling and simulation environment. Hence the main outputs of interest in this model are airport revenues, airport costs, average total delays, and airside and runway utilization ratios. Finally, each simulation run covers a period of 15 years, where a year is represented by one day of operation.

6.2.3 Estimation of parameters, behavioral relationships, and assumptions

The following sections discuss in more detail the variables, their relationships and the assumptions made when building the aforementioned model.

6.2.3.1 Traffic Growth Rate and Change in Fleet Mix

As previously discussed, annual changes in demand are modeled through two variables *Traffic Growth Rate* and *Change in Fleet Mix*. *Traffic Growth Rate* impacts the number of aircraft arriving at the airport, while *Change in Fleet Mix* changes the percentage of small and medium aircraft (the only two aircraft categories modeled in this work) that the airport needs to accommodate. Due to uncertainty in the demand forecast, two demand scenarios are created. Table 30 provides the ranges for each variable and demand scenario. These ranges are based upon the aircraft operations and fleet mix forecasts provided in the T.F. Green Airport Master Plan [197].

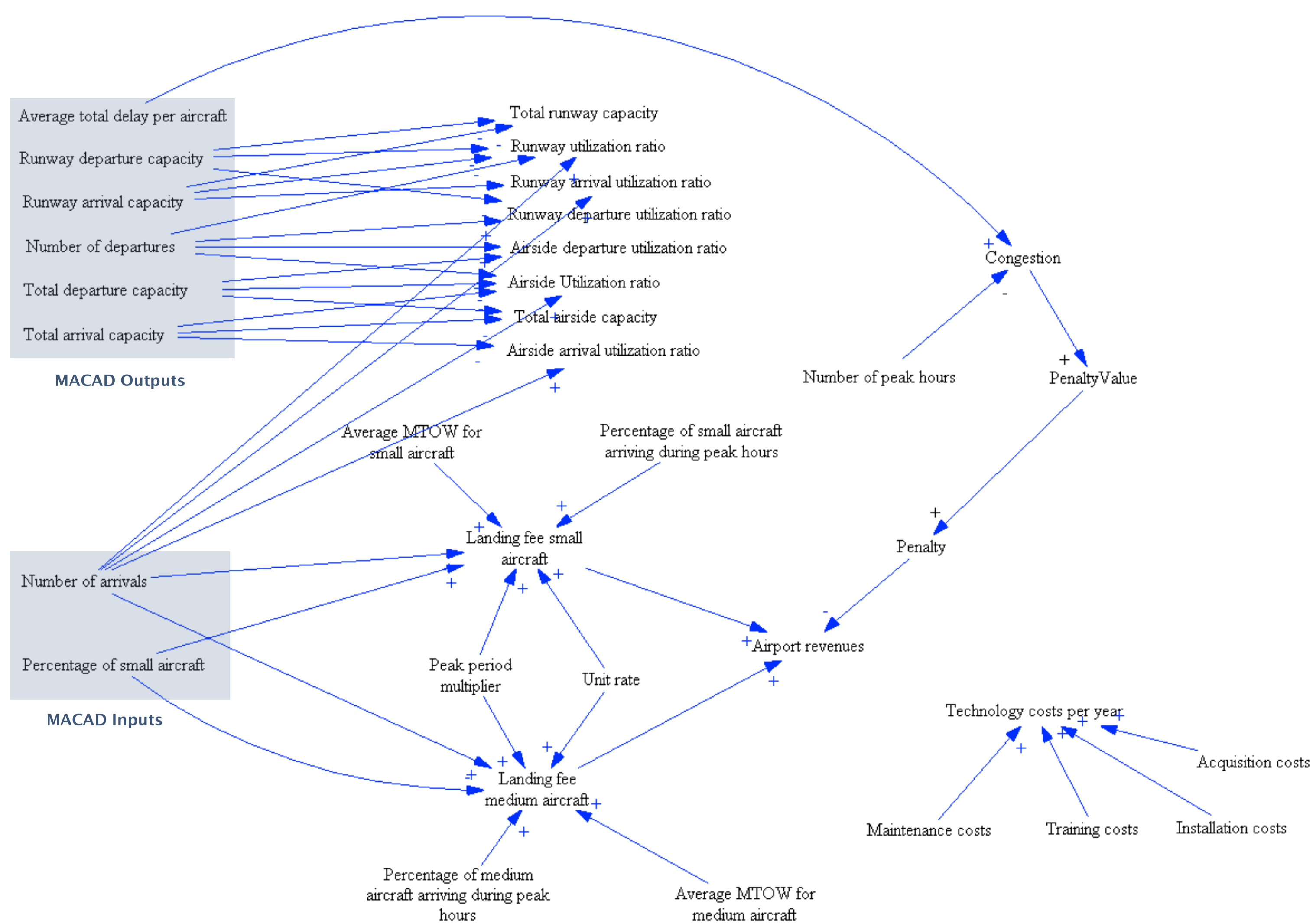


Figure 86: System dynamics model under consideration.

Table 30: Change in demand scenarios

Scenario	Variable descriptions	Ranges	Distribution
LOW	Annual traffic growth rate	1% to 3%	Uniform
	Annual change in % of small aircraft arriving	-3.5% to -1.5%	Uniform
HIGH	Annual traffic growth rate	2% to 4%	Uniform
	Annual change in % of small aircraft arriving	-6.5% to -3.5%	Uniform

6.2.3.2 Delays and Congestion

A factor representative of the long-term growth of congestion at airports is the utilization ratio [74]. The utilization ratio ρ is commonly defined as "the average demand rate over a specified period of time divided by the average capacity over that time" [74], where the demand rate represents the number of movements per day (Equation 16). Congestion can be studied at two levels: the airside level and the runway level, as discussed below.

At the airside level: At the airside level, the utilization ratio can be defined as:

$$\rho_{\text{airside}} = \frac{\text{Number of departures} + \text{Number of arrivals}}{\text{Total departure capacity} + \text{Total arrival capacity}} \tag{13}$$

where the arrival and departure capacities correspond to the maximum number of arriving and departing aircraft, respectively, that the airport can accommodate daily under the configuration considered. *Number of departures*, *Number of arrivals*, *Total departure capacity* and *Total arrival capacity* are all outputs of MACAD. The information provided by MACAD also enables the calculation of utilization ratios for both departure and arrival operations, as shown in Equations 40 and 41. These formulations help identify whether congestion occurs primarily on the arrival or departure side.

$$\rho_{\text{AirsideDep}} = \frac{\text{Number of departures}}{\text{Total departure capacity}} \tag{14}$$

$$\rho_{\text{AirsideArr}} = \frac{\text{Number of arrivals}}{\text{Total arrival capacity}} \tag{15}$$

At the runway level: At the runway level, the utilization ratio can be defined as:

$$\rho_{\text{runway}} = \frac{\text{Number of departures + Number of arrivals}}{\text{(Runway dep. capacity + Runway arr. capacity)} \cdot \text{Operating hours}} \tag{16}$$

where the runway departure and arrival capacities correspond to the number of arrivals and departures per hour that the runway can accommodate under an even mix of operations (equal number of arrivals and departures). Similarly to the airside level, utilization rations can be determined for both departure and arrivals, as shown in Equations 17 and 18.

$$\rho_{\text{RunwayDep}} = \frac{\text{Number of departures}}{\text{Runway departure capacity} \cdot \text{Operating hours}} \tag{17}$$

$$\rho_{\text{RunwayArr}} = \frac{\text{Number of arrivals}}{\text{Runway arrival capacity} \cdot \text{Operating hours}} \tag{18}$$

Congestion can also be represented, as in [225], as the number of hours of waiting time per peak hour of traffic. While many definitions exist for what constitutes a peak-hour, peak hours are defined in this work based on the pattern of traffic shown in Figure 87. Hence traffic peak hours are set as 6:00-7:00, 9:00-10:00, 12:00-13:00, 14:00-1500 and 17:00-18:00 Eastern Standard Time (EST) and represent times of the day when the number of operations is ~30% higher than the hourly average of traffic. Finally, because the percentage of traffic for each hour of the day is fixed throughout the simulation (Table 27), traffic hours are assumed to remain the same, independently of changes in traffic. In the model, congestion at the airside and runway levels is given by Equations 19 and 20, respectively:

$$\text{Congestion}_{\text{airside}} = \frac{\text{Average total delay (per aircraft)}}{5} \tag{19}$$

$$\text{Congestion}_{\text{runway}} = \frac{\text{Average delay due to runway congestion (per aircraft)}}{5} \tag{20}$$

To further investigate the relationship between delays and utilization ratio at the airside level, MACAD is run multiple times using a Latin Hypercube Design of Experiments (DOEs) (400 experiments repeated 200 times). The model inputs used to run the DOE,

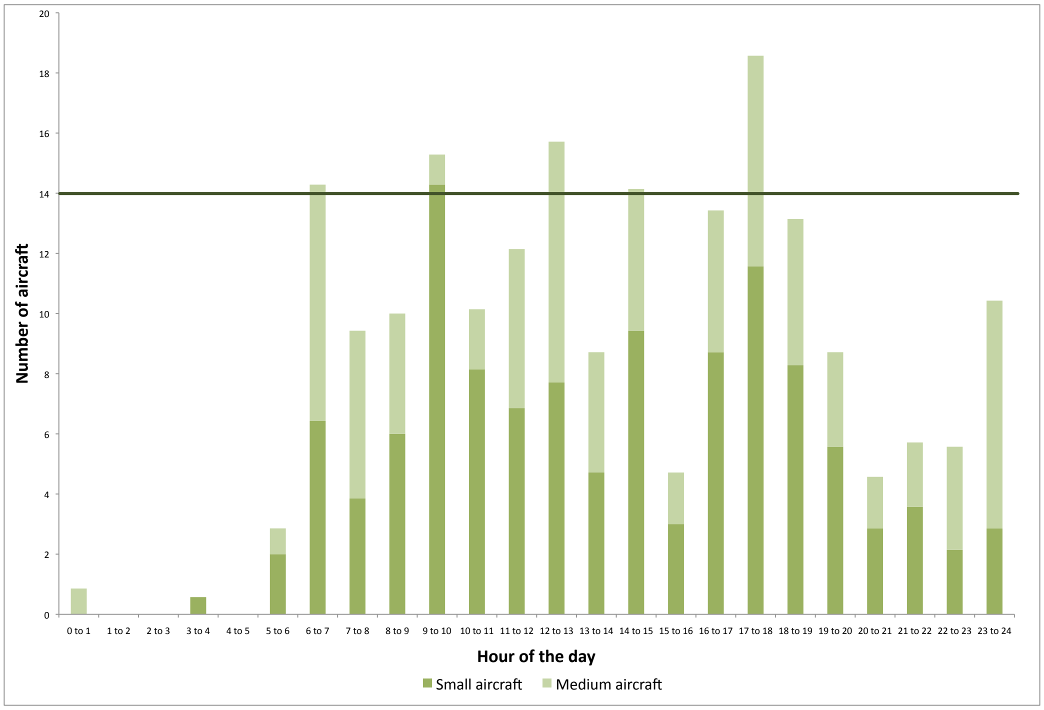


Figure 87: Hourly-based average number of flights for each aircraft category.

along with their descriptions, baseline values, and respective ranges and units are summarized in Table H.1. The FileWrapper created to rapidly and automatically run MACAD under different sets of values can be found in Appendix C.

The resulting figure (Figure 88) illustrates the exponential relationship between average total delay and airside utilization ratio. In particular, it highlights the existence of a pareto front for which the average total delay is minimized and the utilization ratio is maximized.

Table 31: Model variable descriptions, baseline values, ranges and units

Variable descriptions	**Baseline**	**Ranges**	**Units**
Total number of arriving aircraft	99	90-150	Aircraft
Percentage of small aircraft arriving	59	50-80	Percent
Approach speed of small aircraft	110	90-130	knots
Approach speed of medium aircraft	135	110-150	knots
Arrival runway occupancy time for small aircraft	40	20-80	seconds
Arrival runway occupancy time for medium aircraft	45	20-100	seconds
Departure runway occupancy time for small aircraft	49	20-100	seconds
Departure runway occupancy time for medium aircraft	55	20-100	seconds
Arrival taxi average	5	2-10	min
Departure taxi average	5	5-14	min
Minimum separation on approach for a small aircraft following a small aircraft	3	1-6	nmi
Minimum separation on approach for a small aircraft following a medium aircraft	4.5	1-9	nmi
Minimum separation on approach for a medium aircraft following a small aircraft	3	1-6	nmi
Minimum separation on approach for a medium aircraft following a medium aircraft	3.5	1-9	nmi
Minimum inter-departure separation for a small aircraft following a small aircraft	1	0.5-3	nmi
Minimum inter-departure separation for a small aircraft following a medium aircraft	1	0.5-3	nmi
Minimum inter-departure separation for a medium aircraft following a small aircraft	1	0.5-4	nmi
Minimum inter-departure separation for a medium aircraft following a medium aircraft	1	0.5-4	nmi
Minimum distance of the next arrival for a departing aircraft to start rolling	5	2-8	nmi

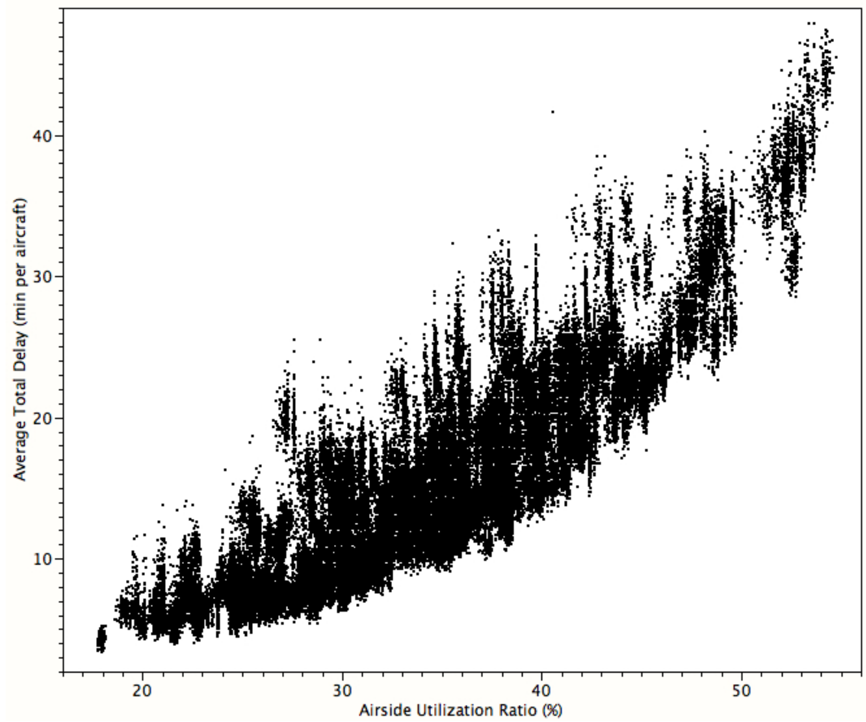


Figure 88: Average total delay (in minute per aircraft) as a function of airside utilization ratio.

Similarly, the relationship between the average delay due to runway congestion and runway utilization ratio is studied by running a Latin Hypercube DOE (400 experiments repeated 40 times) with only two model inputs allowed to vary (Table 32). Again, the resulting figure illustrates the exponential relationship between average delay due to runway congestion and runway utilization ratio (Figure 89).

Table 32: Model variable descriptions, baseline values, ranges and units

Variable descriptions	Baseline	Ranges	Units
Total number of arriving aircraft	99	50-300	Aircraft
Percentage of small aircraft arriving	59	10-90	Percent

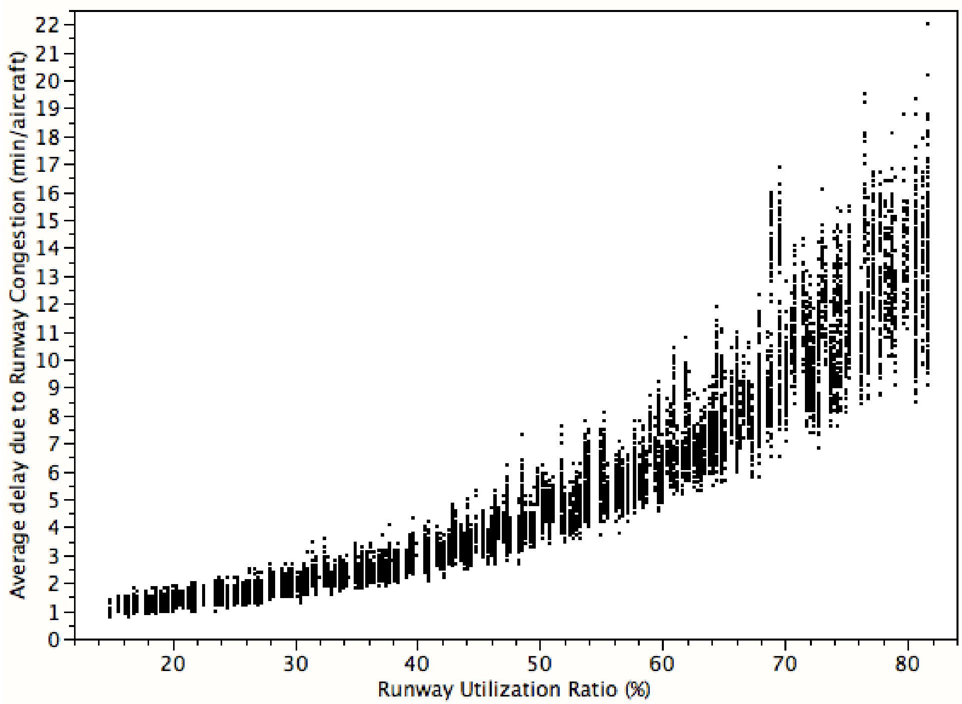


Figure 89: Average delay due to runway congestion (in minute per aircraft) as a function of runway utilization ratio.

Both runway and airside pareto fronts provide information as to the origin of congestion and delays. Hence, the case where runway congestion remains low for high runway utilization ratios while airside congestion reaches high values for low airside utilization ratios may indicate that delays occur at the apron or gate levels. Such delays could be caused by an inadequate number or allocation of gates. The number of gates and the type of aircraft they can accommodate being fixed in this modeling environment, there may be instances, as in the case of a significant increase in the number of medium aircraft for example, where the number of gates that can accommodate these aircraft is insufficient. Such a situation would lead to an increase in the average total delays but not in an increase in delays due to runway congestion. This information can also help identify the technology(ies) that should be pursued. Hence, in the case of strong delays due to runway congestion, investing in technologies that have an impact on inter-departure or arrival-departure separation could be particularly beneficial. Similarly, high values in average total delays could be reduced by targeting technologies that help reduce taxi time. Such technologies would enable higher traffic levels and therefore higher revenues.

6.2.3.3 Airport Revenues

Airport revenues stem from the collection of landing fees. The landing fees schema is inspired from the congestion pricing model in place at Brussels airport (Equation 21) and discussed in [74].

$$\text{Landing Fee} = T \cdot P \cdot W \tag{21}$$

where:

Table 33: Variable descriptions for Equation 21

Variables	Descriptions
T	unit rate specified in U.S. dollars per 1000 lbs
P	peak period multiplier
W	Maximum Take-off Weight (MTOW) of the aircraft in lbs

T is the rate currently used at T. F. Green airport and is equal to \$1.02 per 1000 lbs of landed weight [334]; P is set equal to 1.5 for flights arriving during 6:00-7:00, 9:00-10:00, 12:00-13:00, 14:00-15:00, and 17:00-18:00 Eastern Standard Time (EST), and to 1.0 for all other time-periods; Because this model does not track each aircraft individually, two values of W are used to represent both small and medium aircraft categories. Hence W_{small} is set to 38.79 metric tons or 85,517 lbs (MTOW of an Embraer 175) and W_{medium} is set to 56.45 metric tons or 124,451 lbs (MTW of a B737-300).

Airport revenues are thus divided between landing fees generated from small aircraft operations and landing fees generated from medium aircraft operations. The corresponding equations are as follows:

$$\text{LF}_{small} = T \cdot W_{small} \cdot \%Small \cdot NbACArr\left[(P-1) \cdot \%Small_{PH} + 1\right] \tag{22}$$

$$\text{LF}_{medium} = T \cdot W_{medium} \cdot (1 - \%Small) \cdot NbACArr\left[(P-1) \cdot \%Medium_{PH} + 1\right] \tag{23}$$

where:

Table 34: Variable descriptions for Equations 22 and 23

Variables	Descriptions
T	unit rate specified in U.S. dollars per 1000 lbs
P	peak period multiplier
W_{small}	representative MTOW for small aircraft (in lbs)
W_{medium}	representative MTOW for medium aircraft (in lbs)
$\%Small$	percentage of small aircraft landing at the airport
$NbACArr$	total number of aircraft arriving at the airport
$\%Small_{PH}$	percentage of small aircraft arriving during peak hours (expressed as a percentage of the number of small aircraft)
$\%Medium_{PH}$	percentage of small aircraft arriving during peak hours (expressed as a percentage of the number of medium aircraft)

Airport revenues are also sensitive to levels of congestion. Hence, it is assumed that, when airside congestion reaches a pre-defined threshold, the airport then faces a loss in revenues (Equation 24).

$$\text{Revenues} = \frac{\text{LF}_{small} + \text{LF}_{medium}}{\text{Penalty}} \tag{24}$$

where the penalty value is defined as (Equation 25):

$$\text{Penalty value: } \mathcal{P}(\text{congestion}) = \begin{cases} 1 & \text{cong.} < \text{cong. threshold} \\ 1 - 0.5 \cdot \cos(\pi \cdot \frac{\text{cong.}}{\text{cong.}_\infty}) & \text{cong.} \geqslant \text{cong. threshold} \end{cases} \tag{25}$$

As discussed in Section 6.2.2, the outputs from the modeling and simulation environment are representative of one day of operations for a given year. While this is acceptable to study performance metrics such as daily delay, congestion or utilization ratio, it is less convenient when looking at financial indicators such as revenues. It is thus necessary to translate the revenues generated by the System Dynamics model into yearly figures. However, doing so cannot be done by multiplying the revenues of one day by 365, as it would be equivalent to assuming that the airport accommodates that same amount of traffic throughout the year. In reality, as illustrated in Figure 90, demand grows continuously over the year to reach the level of traffic actually simulated by the System Dynamics model. To avoid over-estimating significantly airport revenues, the annual revenues are calculated by 1) determining the daily change in revenues (in %) between two consecutive years (Equation 26), 2) applying that daily rate throughout the year, 3) summing the resulting daily revenues x_i over 365 days (Equation 27).

$$\text{Daily rate (\%)} = 100 \cdot \left(\frac{\text{Revenues}_j}{\text{Revenues}_i}\right)^{1/365} - 1 \tag{26}$$

$$\sum_{i=0}^{364} x_i \cdot \left(\frac{\text{Daily rate}}{100} + 1\right) \tag{27}$$

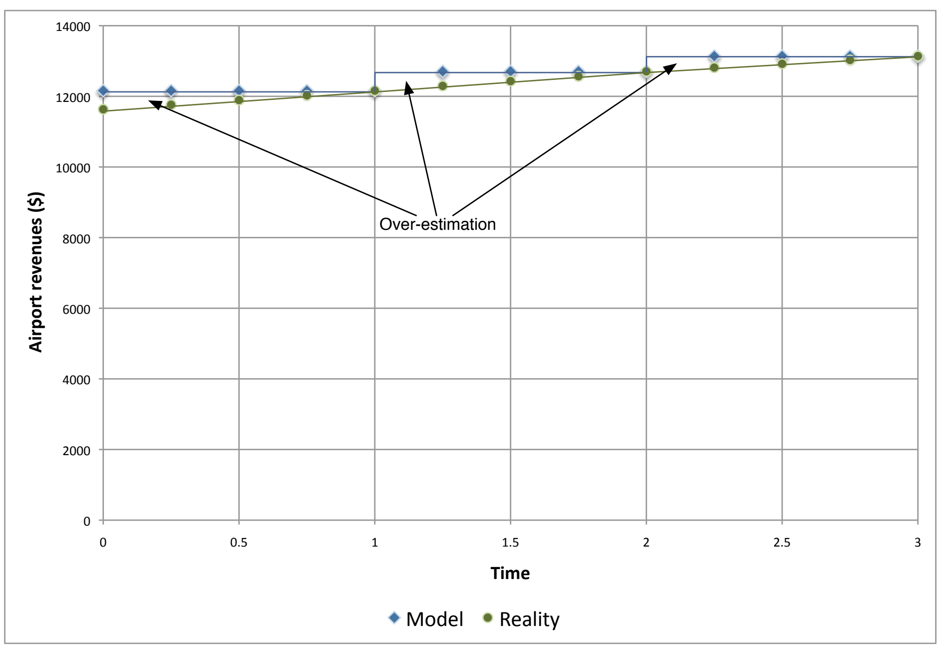


Figure 90: Notional growth in airport revenues as modeled (blue) vs. reality (green).

The revenues obtained through this series of steps may still over-estimate the actual annual revenues, for two main reasons: 1) the growth in traffic is not constant throughout the year, 2) congestion levels may surpass the pre-defined congestion threshold at any given time during the year and lead to lower revenues. However, this calculation process appears as the most acceptable option, given the need to address two distinct levels of granularity (daily operations vs. annual revenues and costs).

6.2.3.4 Airport Costs

The costs incurred by the airport are technology related costs and include acquisition costs (incurred on first year of technology deployment only), installation costs (incurred on first year of technology deployment only and including integration, test and certification), maintenance costs (incurred annually from the year the technology is deployed), training costs (incurred either once or annually from the year the technology is deployed). Not all types of costs are applicable to every technology. Cost estimations are further discussed in Chapter 7.

6.3 General Overview of the Modeling and Simulation Environment

The modeling and simulation environment developed to address the research questions formulated in this work leverages multiple tools and technologies. Figure 91 provides a general overview of the different elements that composed this environment. Each of them is developed to facilitate the implementation of the approach introduced in Chapter 3 and detailed in Chapters 4 through 7.

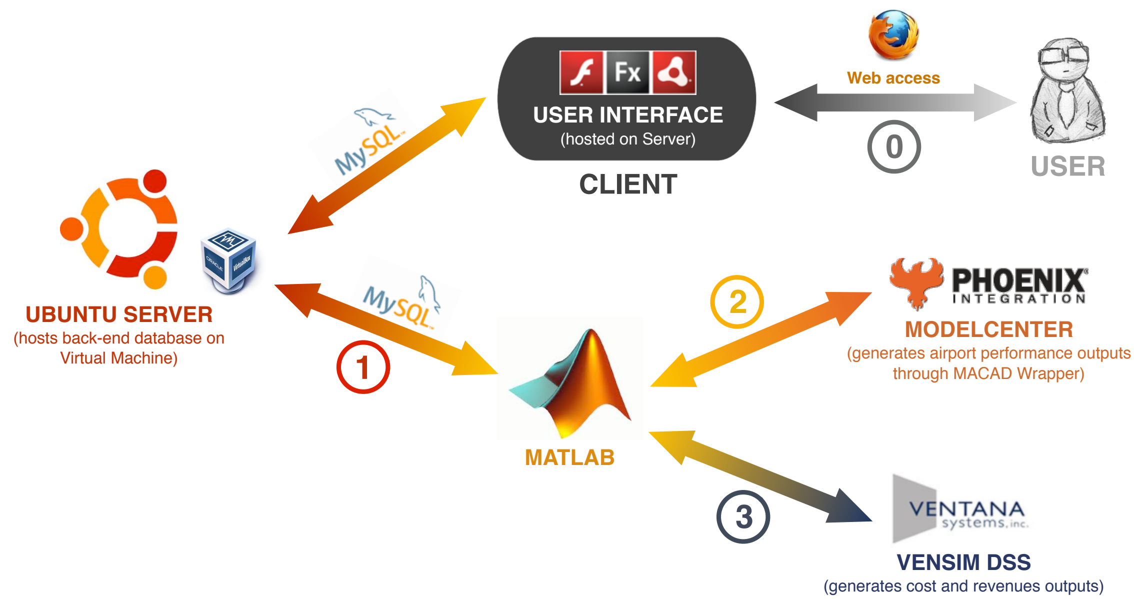


Figure 91: Modeling and simulation environment.

6.3.1 Data Storage

The data needed for the different analyses is stored in SQL tables in a back-end database hosted on a Ubuntu server located on a Virtual Machine. The use of such client-server-based architecture has been chosen for its portability (can be stored on a portable drive), accessibility (through SQL queries from any platform) and, the possibility it offers to quickly and easily update or modify the data. The information is organized in SQL tables according to the Enhanced Entity-Relationship (EER) model provided in Appendix D.2.

6.3.2 Enablers to the Definition of the Technology Space and Technology Impact Assessment

The user interface, developed in Adobe Flash Builder and illustrated in Figure 92, is structured as a web-based application and hosted on the aforementioned Virtual Machine. In particular, this interface is built around the rigorous, structured, traceable and comprehensible process for technology selection described in Chapter 4. Hence, the dependencies between each element and layer of the decomposition (when applicable) discussed in Chapter

4 are integrated into each of the matrices of alternatives following the EER model presented in Appendix D.2. In particular, this application, written in ActionScript, queries the relevant SQL tables to present the user with a down-selected list of technologies based on the options he/she chose in Tables 1, 2 3 and 4. Indeed, the integration of compatibility and dependency relationships between the different options considered in this application makes the down-selection process interactive: each matrix is populated based on the option(s) selected in the matrix from the previous layer. In addition, technologies are filtered based on the year the decision-maker is planning on deploying them. This filter takes into account, for a given year, the availability of operational concepts, functions and enabling technologies, during the down-selection process. This interface also provides the user with the Technology Influence Maps and Scores (Figure 93) discussed in Chapter 5 Section 5.1.1. These allow him/her to rapidly and interactively review the information contained in the technology mappings and gain a better understanding of the technology relationships.

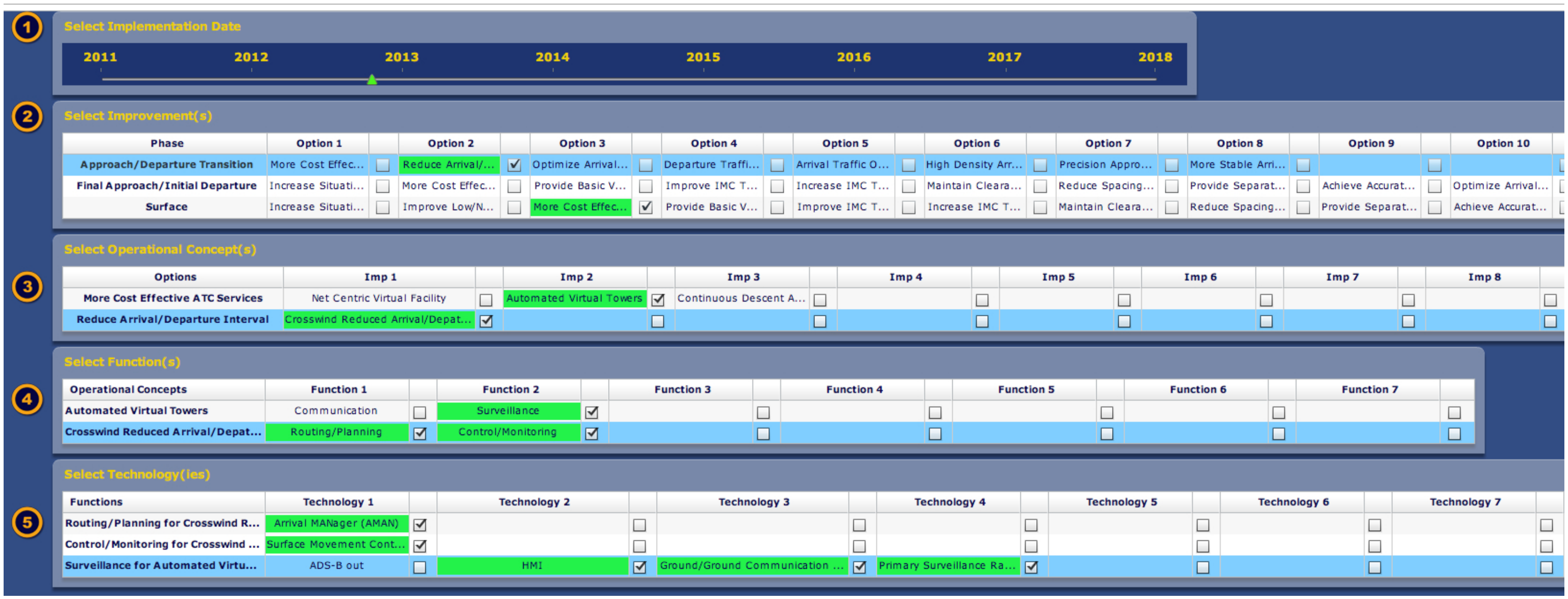


Figure 92: Client interface - Technology selection.

Figure 93: Client interface - Technology Influence Maps and Scores.

6.3.3 Enablers to the Modeling and Simulation Environment and Portfolios Valuation

The models supporting the implementation of Steps #3 and #4 of the proposed approach have been presented independently in this chapter (Sections 6.1 and 6.2). To streamline the analysis, it is important that both MACAD and the System Dynamics model be integrated. This is achieved through Matlab, which is used as the link between the data stored in the database, MACAD (run in ModelCenter by the means of the wrapper provided in Appendix C) and the System Dynamics model developed in Vensim. Hence, Matlab 1) queries the necessary data from the databases using SQL queries, 2) feeds the relevant information to MACAD, runs MACAD through ModelCenter and 3) passes on the necessary MACAD output values to the corresponding System Dynamics variables, runs the SD model and collects the information necessary (revenues, costs, airport performance) to support the valuation and selection of adaptable technology portfolios (as discussed in Chapter 7). The corresponding Matlab files can be found in Appendix F.

The following section discusses how this modeling and simulation environment is used to help address **Research Question 2: How can the need for capacity expansion and resulting technology investments be identified and characterized?**

6.4 Sensitivity Analysis

A sensitivity analysis is performed as a means to identify the factors that drive the need for capacity expansion. This analysis is conducted at two-levels, system level and technical level. At the system level, the sensitivity analysis is carried out on the SD model outputs of interest. The results of this first sensitivity analysis are provided in Section 6.4.1. Once the key system variables are identified, a sensitivity analysis is further performed on those, using the MACAD airport model. In particular, a Latin Hypercube DOE is used to identify the sensitivity of the key system variables to the technical variables. The results of this second sensitivity analysis are discussed in Section 6.4.2

6.4.1 Sensitivity Analysis at the System Level

The System Dynamics model is run 5000 times during which inputs are allowed to vary simultaneously according to the distributions provided in Table 35. The ranges chosen for each of these distributions correspond to the span of the response variables obtained after running the DOE on the input variables (Figure 80).

Table 35: Model variable descriptions, baseline values, ranges and units

Variable descriptions	Distribution	Units
Total arrival capacity	UNIFORM(215.59, 461.36)	aircraft
Total departure capacity	UNIFORM(275.15, 705.255)	aircraft
Average total delay	UNIFORM(4.2825, 44.11)	minute per aircraft
Percentage of small aircraft arriving	UNIFORM(50, 80)	percentage
Number of departures	UNIFORM(90, 150)	aircraft
Number of arrivals	UNIFORM(90, 150)	aircraft
Congestion threshold	UNIFORM(0.05, 0.1)	hr per peak hr

The sensitivity of the outputs of interest, namely *Revenues*, *Airside Utilization Ratio*, and *Total Capacity* to the different variables is further explored using JMP. The results of this first sensitivity analysis are provided in Table 36. The corresponding pareto plots can be found in Appendix D.3.

Table 36: Results of the sensitivity analysis on the the outputs of interest (subset of model variables in order of decreasing influence)

Revenues	Airside Utilization Ratio	Total Capacity
Number of arrivals	Total departure capacity	Total departure capacity
Percentage of small aircraft	Total arrival capacity	Total arrival capacity
Average total delay per aircraft	Number of departures	
	Number of arrivals	

6.4.2 Sensitivity Analysis at the Technical Level

A second sensitivity analysis is thus conducted, when relevant, on the variables that have the strongest influence on *Revenues*, *Airside Utilization Ratio*, and *Total Capacity*. The results are provided in Table 37 with the corresponding figures in Appendix D.4.

Table 37: Results of the sensitivity analysis on the the outputs of interest (subset of model variables in order of decreasing influence)

Average Total Delay
Number of aircraft arriving per day
Min. separation between arriving and departing aircraft
Percentage of small aircraft
Approach speed of small aircraft
Total Departure Capacity
Min. separation between arriving and departing aircraft
Min. inter-departure separation between two small aircraft
Min. inter-departure separation between medium and small aircraft
Min. inter-departure separation between small and medium aircraft
Total Arrival Capacity
Min. separation between arriving and departing aircraft
Approach speed of small aircraft
Min. separation on approach between two small aircraft
Arrival runway occupancy time for small aircraft

6.4.3 Observations

First and foremost, it is important to remember that the results presented in Tables 36 and 37 depend on the ranges chosen as well as on the structure and assumptions of both airport and SD models. With this in mind, a few observations can be made regarding both sensitivity analyses. First, revenues are more sensitive to traffic (number of arriving aircraft and traffic mix) than to the average total delay per aircraft, or congestion. This is true for the range of congestion threshold values chosen. Second, the total airside capacity is more sensitive to departure capacity and departure operations, than it is to arrival operations. Consequently, efforts to increase the airside capacity should focus more particularly on the departure side of airport operations.

From a technical perspective, the minimum separation between arriving and departing aircraft has a strong impact on total departure and arrival capacities, as well as on the average total delay experienced per aircraft. Hence, technologies reducing the minimum separation between arriving and departing aircraft should be pursued to help reduce delays and increase airside capacity. Similarly, the minimum inter-departure separation between aircraft seems to have a stronger influence on departure and arrival capacities than does the minimum separation between aircraft on approach.

6.4.4 Discussion on Hypothesis 2 and Hypothesis Verification

Hypothesis 2: System Dynamics modeling provides a means to identify the key factors driving the need for capacity expansion, and the resulting technology investments.

The present chapter introduced the airport and System Dynamics models developed for this work. In particular, it has emphasized the integration of both models as a means to support the identification of the system and technical factors that drive the need for capacity expansion. Hence, this integrated environment provides the necessary framework and level of abstraction to characterize the nature (demand or technological) of these key factors and differentiate between them. The two consecutive sensitivity analyses conducted on the models have shown that, as expected, the need for capacity expansion is mostly driven by traffic/demand variables. However, they have also shown that this need can be addressed, at the technological level, with technologies having an impact of departure operations and minimum separation between arriving and departing aircraft. Such information can then be used by the decision maker to choose among the many technologies available to him/her. In light of this discussion, it appears that **Hypothesis 2 is verified**.

The airport and System Dynamics models allow the user to capture the changes in the system and identify the factors responsible for these changes. However, as previously addressed, such capability and knowledge are only valuable if integrated into the definition and selection of technology portfolios. The following chapter discusses how portfolios are defined so that they can address change and how such capability is valued.

CHAPTER VII

STEP #4: VALUATION AND SELECTION OF ADAPTABLE PORTFOLIOS

The approach described in this dissertation is now implemented to evaluate the performance and strategic benefits of defining adaptable technology portfolios in the case of a change in requirements at airports. In particular, two airports are considered: one for which a significant technology equipage is already in place or planned, and for which there is not much room left for flexibility; and a second one that has not significantly committed to any technology portfolio. These two airports are actually the same airport (described in Section 6.1.1), but with different levels of equipage. Hence, the “first” airport (referred to as *Airport #1*) is one with today’s traffic and technologies, while the “second” airport (referred to as *Airport #2*) is the same regional airport but with the traffic and technologies of a few decades ago. Changes in requirements for both airports will come from a change in the aircraft mix as well as the number of aircraft arriving at the airport (ad discussed in Section 7.2). In other words, both airports are submitted to the same traffic forecast in terms of percentage growth (or decrease) in small aircraft as well as in arriving aircraft. The following sections (section 7.1 and 7.2) describe the different technology investment scenarios available to each airport, as well as the traffic scenarios under which both airports operate. These define the space within which the proposed approach is implemented (Section 7.3). Then, Section 7.4 discusses the formulation of the technology portfolios used in this approach. Finally, Section 7.5 introduces the implementation of Real Options Analysis to help assess the flexibility and strategic value of the technology portfolios considered.

7.1 Formulation of Investment Scenarios

The investment window considered span over 15 years. During these 15 years, airports can decide to invest, or not, at years 5 and 10. The flexibility in investment sequence is thus illustrated by the four following investment scenarios (Figure 94):

- **Scenario #1:** the airport does not invest in new technologies and thus carries its current equipage over the 15 years
- **Scenario #2:** the airport invests in a given technology portfolio at Year 5 only
- **Scenario #3:** the airport invests in a given technology portfolio at Year 10 only
- **Scenario #4:** the airport invests first in a given technology portfolio at Year 5 and later complement that initial technology portfolio with technologies available at Year 10 and earlier.

These scenarios illustrates the airport's investment flexibility. Hence, if the airport had envisioned to invest at both Year 5 and Year 10 (Scenario #4), it may deviate from that scenario and consider Scenarios #2 or #3 instead, in the case where demand does not materialize as expected. The same is also true in the opposite case. The formulation of this problem from a Real Options perspective, as further discussed in Section 7.5, offers the airport the possibility to alter investment strategies.

7.2 Formulation of Traffic Scenarios

As discussed in Chapter 6, annual changes in traffic are modeled through two variables *Number of arrivals* and *Percentage of small aircraft*, based on the traffic scenarios described in Table 38. This allows the decision maker to study the performance and rankings of the technology portfolios under different traffic conditions.

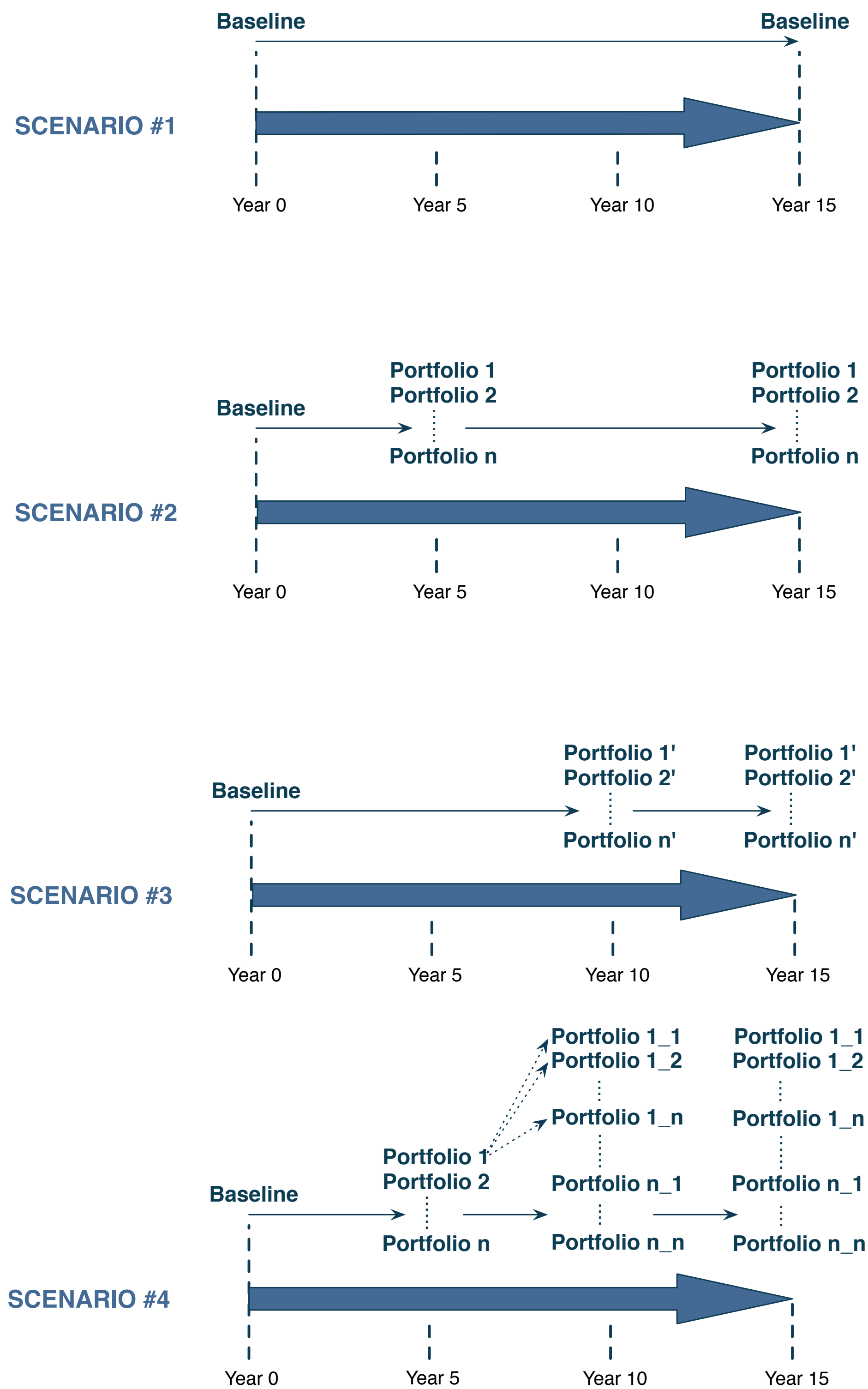


Figure 94: Investment scenarios.

Table 38: Change in demand scenarios

Scenario	Variable descriptions	Ranges	Distribution
LOW	Annual traffic growth rate	1% to 3%	Uniform
	Annual change in % of small aircraft arriving	-3.5% to -1.5%	Uniform
HIGH	Annual traffic growth rate	2% to 4%	Uniform
	Annual change in % of small aircraft arriving	-6.5% to -3.5%	Uniform

7.3 Summary of potential scenarios of interest

The investment and traffic scenarios, along with the two types of airports considered, define the space within which the proposed approach is implemented. This *scenario space* is further represented in the matrix of alternatives below. In particular, the scenario investigated in Chapter 8 is highlighted in green.

Table 39: Morphological matrix of scenarios of interest

Variable descriptions	Alt. #1	Alt. #2	Alt. #3	Alt. #4
Type of airport	Airport #1	Airport #2		
Investment scenario	Scenario #1	Scenario #2	Scenario #3	Scenario #4
Change in aircraft mix	LOW	HIGH		
Change in number of arr. ac	LOW	HIGH		

7.4 Formulation of Technology Portfolios

Due to the number of scenarios and investment options considered (Figure 94), the formulation of technology portfolios represents a huge combinatorial problem. Indeed, considering only 4 candidate technologies for investment (T_1, T_{11}, T_{13} and T_{20}) leads to the formulation of $\sum_{k=1}^{4} \frac{4!}{k!(4-k)!} = 15$ distinct potential technology portfolios (assuming no particular relationships between technologies), as illustrated in Figure 95.

The 35 technologies included in this work would in turn result in $3.436 * 10^{10}$ distinct portfolios (assuming no particular relationships between technologies). Consequently, for

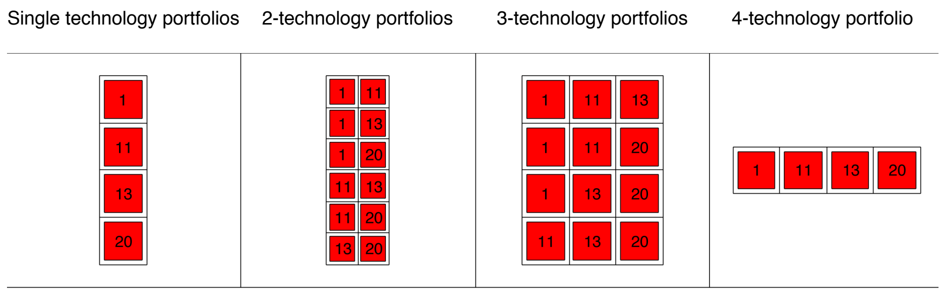


Figure 95: Portfolios generated from 4 technologies (each row of each cell array represents a distinct portfolio).

practicality purposes, a small subset of these 35 technologies is considered. The technologies belonging to that subset are chosen according to the following criteria:

- they illustrate each of technology relationships identified in Chapter 5: synergistic, unilateral influence and no influence
- they have an impact on the key factors identified by the sensitivity analyses conducted in Chapter 6
- they are applicable to the airport model under consideration. Hence the capacity-enhancing technology PRM is not selected because 1) "operating dual simultaneous independent approaches is not currently possible and PRM would not provide any benefits" [197], 2) only one runway is modeled in MACAD

The technologies chosen to be part of the baseline or to be considered for future investment options are listed in Tables 40 and 41, for *Airport #1* and *Airport #2*, respectively. Hence, the technologies considered for baseline and future investment options at airport #2 are the same as at airport #1, except that some technologies marked in the *Baseline* category in Table 40 belong to the *Future investment* category in Table 41. A description of theses technologies can also be found in Appendix E.

These technologies impact the system in different fashions. Some technologies have a direct impact on a given technical metric (i.e. Departure MANager on departure taxi

Table 40: Technologies considered for baseline and future investment options at airport #1

ID	Technology Name	Baseline	Future Investment
T_0	Multi-Sensor Data Processor (MSDP)	X	
T_1	Primary Surveillance Radar (PSR)	X	
T_3	Multilateration (MLAT)		X
T_4	Surface Movement Radar (SMR)	X	
T_5	Legacy Secondary Surveillance Radar (SSR)	X	
T_{10}	Human Machine Interface (HMI) related Technologies	X	
T_{11}	Ground/Ground Communication	X	
T_{21}	Switchable Center Line Lights and Stop Bars	X	
T_{27}	Instrument Landing System (ILS)	X	
T_{28}	Departure MANager (DMAN)		X
T_{29}	Surface MANager (SMAN)		X
T_{30}	Arrival MANager (AMAN)		X
T_{31}	Current Air/Ground Datalink Broadcast Technologies	X	
T_{32}	Current Air/Ground Datalink Point-to-point Technologies	X	

Table 41: Technologies considered for baseline and future investment options at airport #2

ID	Technology Name	Baseline	Future Investment
T_0	Multi-Sensor Data Processor (MSDP)	X	
T_1	Primary Surveillance Radar (PSR)	X	
T_3	Multilateration (MLAT)		X
T_4	Surface Movement Radar (SMR)	X	
T_5	Legacy Secondary Surveillance Radar (SSR)		X
T_{10}	Human Machine Interface (HMI) related Technologies	X	
T_{11}	Ground/Ground Communication	X	
T_{21}	Switchable Center Line Lights and Stop Bars		X
T_{27}	Instrument Landing System (ILS)	X	
T_{28}	Departure MANager (DMAN)		X
T_{29}	Surface MANager (SMAN)		X
T_{30}	Arrival MANager (AMAN)		X
T_{31}	Current Air/Ground Datalink Broadcast Technologies	X	
T_{32}	Current Air/Ground Datalink Point-to-point Technologies	X	

average). Others do not have such a direct impact but are nevertheless necessary to the functionality of other technologies that do. Finally, some technologies, in particular lighting systems, have an impact on the traffic itself in the sense that such technologies can either limit or extent the schedule under which the airport operates. Hence, an airport with no lighting system will not be able to accommodate flights after dusk.

The Technology Impact Matrix (TIM) for these technologies is pictured in Table 43, with the corresponding metrics listed in Table 44. The k-factors provided in this table represent an improvement (in percentage) of the baseline for the airport considered (Table 42). Hence, it is assumed that no technology contributes in degrading the system. In the case where the technology belongs to the baseline, its impact is assumed to be captured in the baseline values. The number of arriving aircraft for *Airport #1* represents the level of traffic currently experienced by the airport. The number of arriving aircraft for *Airport #2* represents the traffic experienced by the airport in 1990 in terms of air carrier and commuters/air taxi [197].

Due to uncertainty in the performance of these technologies, impacts are modeled as uniform distributions with ranges either guessed or based upon information from the literature (when available). In the case where no data is available from the literature, efforts are made to ensure that the estimations provided account for the relative performance of a technology with respect to another. Hence, surveillance systems known (or expected) to provide better accuracy than others are modeled as having a stronger impact of approach separation, for example. In the case where no lighting technologies are present, a modified schedule is applied to the airport model. This schedule is such that no flights take-off or land after 5pm. This hour corresponds to the time of the day when sunlight is too low to guarantee safe runway operations. This hour is considered to be the same throughout the year, based on the assumptions that if no flights are scheduled after this hour during winter, none will be scheduled after that hour during summer either.

Table 42: Baseline variables, values, and units for airport #1 and #2

Variable descriptions	Airport #1	Airport #2	Units
Total number of arriving aircraft	99	60	Aircraft
Percentage of small aircraft arriving	59	70	Percent
Approach speed of small aircraft	110	110	knots
Approach speed of medium aircraft	135	135	knots
Arrival runway occupancy time for small aircraft	40	40	seconds
Arrival runway occupancy time for medium aircraft	45	45	seconds
Departure runway occupancy time for small aircraft	49	49	seconds
Departure runway occupancy time for medium aircraft	55	55	seconds
Arrival taxi average	5	4	min
Departure taxi average	5	4	min
Minimum separation on approach for a small aircraft following a small aircraft	3	3.5	nmi
Minimum separation on approach for a small aircraft following a medium aircraft	4.5	5	nmi
Minimum separation on approach for a medium aircraft following a small aircraft	3	3.5	nmi
Minimum separation on approach for a medium aircraft following a medium aircraft	3.5	4	nmi
Minimum inter-departure separation for a small aircraft following a small aircraft	1	1.5	nmi
Minimum inter-departure separation for a small aircraft following a medium aircraft	1	1.5	nmi
Minimum inter-departure separation for a medium aircraft following a small aircraft	1	1.5	nmi
Minimum inter-departure separation for a medium aircraft following a medium aircraft	1	1.5	nmi
Minimum distance of the next arrival for a departing aircraft to start rolling	5	5.5	nmi

Table 43: Technology Impact Matrix for the technologies considered for baseline and future investment options (the k-factors are percentages and represents improvements from the baseline)

Technology ID	Metric																
	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	M_{11}	M_{12}	M_{13}	M_{14}	M_{15}	M_{16}
T_0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_1	-	-	-	-	-	-	-	-	12 - 14	8 - 10	12 - 14	10 - 12	-	-	-	-	-
T_3	-	-	-	-	-	-	-	-	15-17	10-12	15-17	13-15	15-20	15-20	15-20	15-20	8-12
T_4	-	-	-	-	7 - 9	8 - 10	4 - 6	4 - 6	-	-	-	-	-	-	-	-	-
T_5	-	-	-	-	-	-	-	-	13 - 15	9 - 11	13 - 15	12 - 14	-	-	-	-	-
T_{10}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{11}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{21}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{27}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{28}	-	-	-	-	15-18	15-18	-	8-12	-	-	-	-	-	-	-	-	8-12
T_{29}	-	-	-	-	13-15	13-15	9-11	9-11	-	-	-	-	-	-	-	-	-
T_{30}	-	-	11-13	10-12	-	-	9-11	-	-	-	-	-	-	-	-	-	8-12
T_{31}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{32}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 44: Metrics considered

ID	Metric
M_0	Approach speed of small aircraft
M_1	Approach speed of medium aircraft
M_2	Arrival runway occupancy time for small aircraft
M_3	Arrival runway occupancy time for medium aircraft
M_4	Departure runway occupancy time for small aircraft
M_5	Departure runway occupancy time for medium aircraft
M_6	Arrival taxi average
M_7	Departure taxi average
M_8	Min. separation on approach between two small aircraft
M_9	Min. separation on approach between small and medium aircraft
M_{10}	Min. separation on approach between medium and small aircraft
M_{11}	Min. separation on approach between two medium aircraft
M_{12}	Min. inter-departure separation between two small aircraft
M_{13}	Min. inter-departure separation between small and medium aircraft
M_{14}	Min. inter-departure separation between medium and small aircraft
M_{15}	Min. inter-departure separation between two medium aircraft
M_{16}	Min. separation between arriving and departing aircraft

The following paragraphs discuss in more detail the formulation of technology portfolios for each of the scenarios identified above:

- **Scenario #1** in this scenario, the airport does not invest in any technologies. Hence the technologies used are the ones marked in the *Baseline* category in Table 40. Their combined impact on the metrics of interest is not calculated but assumed to be equal to the baseline values provided in Table H.1.

- **Scenario #2:** the airport invests in a given technology portfolio at Year 5 only. In this scenario, the technologies that constitute each candidate portfolio have a deployment date less or equal to Year 5 (2010). Also, the portfolios created account for the technology relationships discussed in Section 5.1.1.2. In particular, if Technology B requires that Technology A be in place, then the portfolios formulated need to have both Technologies A and B. When generating technology portfolios, the algorithm developed (Appendix F) verifies that Technology A is either already in place (included in the baseline), or belongs to the list of new candidate technologies whose deployment date is less or equal to Year 5.

- **Scenario #3:** the airport invests in a given technology portfolio at Year 10 only. The logic used to formulate candidate technology portfolios is the same as for Scenario #2 except that the technologies included need to have a deployment date less or equal to Year 10 (2015)

- **Scenario #4:** the airport is presented with an investment option twice, the first time at Year 5 (2010) and the second time at Year 10 (2015). The formulation of technology portfolios at Year 5 follows the same logic and requirements as in Scenario #2. However, the formulation of technology portfolios at Year 10 (2015) is more complex as the candidate portfolios need to include the technologies acquired at Year 5 (2010)

The following section discusses the formulation of a Real Options framework to help define and embed flexibility in the formulation of technology portfolios, and eventually assess the strategic value, for airports, of embedding that flexibility.

7.5 Formulation of the Real Options Framework

As discussed extensively in Chapter 2, Real Option Analysis provides the framework necessary to integrate, capture and value the flexibility embedded in projects in general, and sequential project investments, in particular. This section follows the four-step process proposed by [63] to address an options problem:

1. Estimate the traditional Net Present Value (NVP without flexibility)

2. Model the uncertainties that drive the value of the investment

3. Build the event tree

4. Value the real options using a replication portfolio approach

7.5.1 Estimation of the traditional NPV

The Net Present Value (NPV) is one of the most commonly used criteria to measure project profitability. It is also the foundation for ROA [63]. It is defined as:

$$NPV = -I_0 + \sum_{t=0}^{T} \frac{R_t - E_t}{(1 + r_f)^t} \tag{28}$$

where:

R_t is the sum of all revenues at year t

E_t is the sum of all expenditures at year t

I_0 is the investment at time zero. I_0 is further discussed in Section 7.5.4

T is the time to expiration

$(1 + r_f)$ is the discount factor, where r_f is the risk-free rate of return. A value for r_f of 8 percent [102] is assumed

Revenues are obtained by following the steps enumerated in Section 6.2.3.3. Cost/expenditure information for each of the technology considered is summarized in Tables 45 and 46. It is based on data gathered from the literature, when available/applicable. It is important to keep in mind that the costs of these technologies are dependent upon many factors, such as [102]:

- the nature of the hardware, as well as the number of sensors, radars, receiver/transmitter stations, etc. necessary: the airfield layout and topology, the existing infrastructure and the surrounding terrain, for example, often influence the number of radars to be installed

- the interface already in place: the number of modifications or adjustments to be made to the existing interface often carry significant testing, validation and certification efforts

- the performance of the technology itself: some SMRs, for example, are better than others, and thus more expensive

- where it is being installed: a radar mounted on a dedicated tower would be more expensive that if it were to be installed on the control tower

- the resources it requires: a SMR, for example, requires a specific power supply and a communication link. Those need to be available at the installation site

Hence, the values provided in these tables represent, at best, estimates. Also, as mentioned in Section 6.2.3.4, acquisition, installation and training costs are one-time costs, while maintenance costs are incurred on a yearly basis once the technology is in place. Airports #1 and #2 are also subjected to additional operating costs of M$4.0 and M$1.5 per year, respectively. These costs are assumed to remain constant throughout the study.

Table 45: Cost information for each of the technologies considered, based on assumed data or data available in the literature [102, 98, 120, 116, 114, 101]

	Technologies						
	T_0	T_1	T_3	T_4	T_5	T_{10}	T_{11}
Acquisition costs ($)	2,216,630[a]	3,913,800[a]	1,056,726[a]	521,840[a]	3,913,800[a]	39,138	50,000[e]
Installation costs ($)	260,920[a]	391,380[a]	404,426 [a]	391,380[a]	391,380[a]	-[f]	15,000[e]
Training costs ($)	130,460[a]	-	130,460[b]	-	-	6,520[d]	-
Maintenance costs ($)	260,920[a]	195,690[a]	110,891[a]	26,092[a]	195,690[a]	6,520[c]	10,000[e]

[a] Data from[102]
[b] Assumed to be the same as for a Multi-Sensor Data Processor
[c] Assumed 5 HMI/CWP (Controller Working Positions) [102]
[d] Assumed training for 5 people [102]
[e] Assumed
[f] included in acquisition costs

Table 46: Cost information for each of the technologies considered, based on assumed data or data available in the literature [102, 98, 120, 116, 114, 101] (continued)

	Technologies						
	T_{18}	T_{27}	T_{28}	T_{29}	T_{30}	T_{31}	T_{32}
Acquisition costs ($)	- [g]	438,345[i]	1,000,000[j]	500,000[j]	1,000,000[j]	97,987[l]	78,390[m]
Installation costs ($)	78,410[h]	523,144[i]	-[k]	-[k]	-[k]	19,597[l]	15678[m]
Training costs ($)	-	-	100,000[j]	100,000[j]	100,000[j]	-	-
Maintenance costs ($)	97,902[h]	103,063[i]	200,000[j]	100,000[j]	200,000[j]	9,798[l]	7,839[m]

[g] Included in installation costs [120]
[h] Data from [120]
[i] For an ILS/DME Cat I for a new runway [101]
[j] Assumed
[k] Assumed included in acquisition costs
[l] Assuming one ground station (ground station site already existing) [114]
[m] Assuming VDL2 ground station (ground station site already existing) [114]

7.5.2 Modeling of the Uncertainty

The driving causes of uncertainty, or sources of risk, identified for the problem at hand are primarily associated with the performance of the technologies selected, and the magnitude of the demand (in terms of number of aircraft and traffic mix) that the airport will have to handle. These, as explained in Chapter 6, have an influence on the financial return of a given portfolio.

As described by Copeland and Antikarov [63], one approach to handle multiple uncertainties and combine them into one estimate is by means of Monte Carlo Analysis. Hence a Monte Carlo simulation is performed (each portfolio run 500 times) to obtain a volatility estimate. Volatility is calculated based on the distribution of cash flows following Mun's [232] formulation (Equation 29):

$$X = ln(\frac{\sum_{i=1}^{n} PVCF_i}{\sum_{i=0}^{n} PVCF_i}) \tag{29}$$

where:

$PVCF_i$ is the present value of future cash flows at different time periods i

X is the forecast distribution

The volatility σ is then defined as the standard deviation of X.

7.5.3 Building of the decision tree

The decision tree identifies the series of real options that can be exercised, when they take place, when they expire, their impact on the remaining present value, and their exercise price [63]. A simple decision tree for this problem is illustrated in Figure 96.

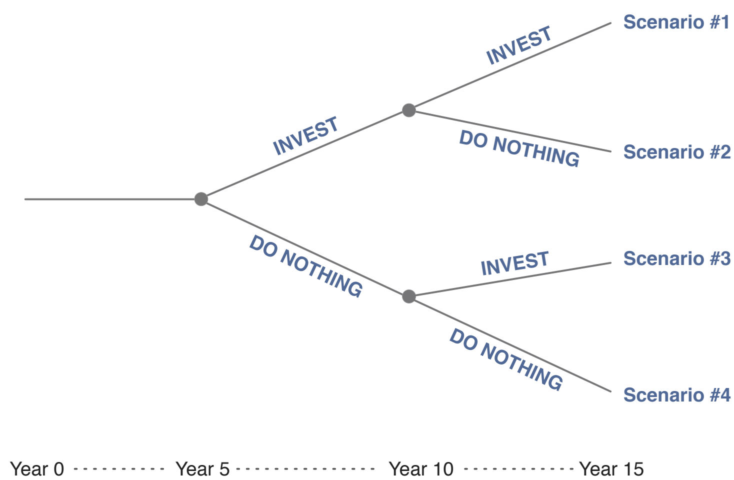


Figure 96: Proposed decision tree.

7.5.4 Valuation of the Real Options

A real option is defined according to the following variables:

- Underlying Asset, S: the present value of the free cash flow generated by deploying a given portfolio
- Exercise/Strike Price, X: the costs associated with the acquisition and installation of the technology portfolio under consideration
- Time to expiration of the option, T: the length of time the option is viable and may be exercised. The time to expiration is 5 years for Scenarios #2 and #4, and 10 years for Scenario #3. Also, this work uses a European option (an option that can only be

used at maturity [304]) because this type of option presents similarities with the way investment decisions are made for this type of problem [222]

- Standard deviation of the value of the underlying risky asset, σ: it represents the riskiness of the asset and is obtained as described in Section 7.5.2
- Risk-free rate of interest over the life of the option, r_f: a value of 8 percent is assumed

As discussed extensively in Chapter 2, in the case of a call option, a buyer of an option has the right to buy the underlying asset from the seller of the option for a certain price. To have this right, the buyer pays a call premium. This call premium is represented, in the context of this research, by the amount of money that the airport pays for a feasibility study prior to any technology investment. The cost of this study is set to \$150,000.

There exist many option valuation models for calculating the value of Real Options. Two well-known models are the continuous-time Black-Scholes model, based on the work of Black and Scholes [31] and Merton [220], and the discrete-time binomial model. Both are discussed in the following sections along with their respective assumptions, advantages and drawbacks.

7.5.4.1 The Black-Scholes model

The Black-Scholes model is provided by the following equation [63]:

$$\text{Value of Call Option: C} = S\,\phi(d_1) - Xe^{-r_f T}\phi(d_2) \tag{30}$$

where :

$d_1 = \frac{ln(\frac{S}{X})+(r_f+\frac{\sigma^2}{2})T}{\sigma\sqrt{T}}$

$d_2 = d_1 - \sigma\sqrt{T}$

$\phi(d)$ is the cumulative normal distribution function

This model relies on six assumptions that limit its applicability to value real options [63]:

1. The option is a European option: it can only be exercised at maturity

2. There is only one source of uncertainty and the variance is known and assumed to be constant

3. The exercise price is known and constant

4. The option is contingent on a single underlying asset: **this restricts the use of the Black-Scholes model to value nested options**

5. The underlying asset does not pay any dividends

6. The risk-free rate is constant and known

7. The process governing the value of the underlying asset follows geometric Brownian Motion

One of the advantages of the Black-Scholes model is that it is a closed-form equation. As such, it enables the quick, exact and easy valuation of a high number of options. Two of its main drawbacks are that it is often seen as a black box and that it cannot be used to solve American options unless modified.

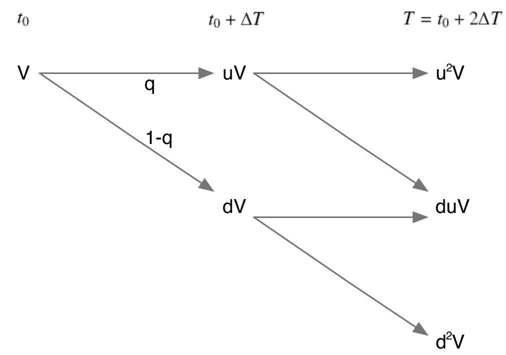
7.5.4.2 The Binomial model

The binomial model assumes that the value of the underlying asset (V) follows a binomial multiplicative diffusion process [26, 171].

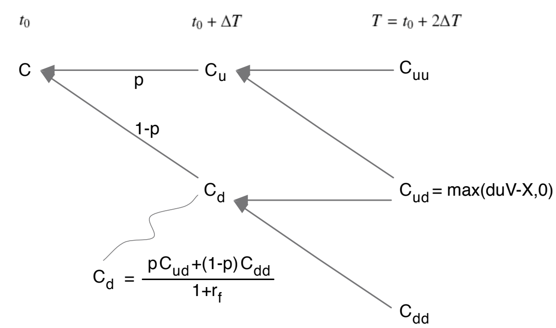
This model requires two binomial trees: one for the underlying asset (Figure97(a)), and one for the option value (Figure 97(b)).

Between t_0 and $t_0 + \Delta T$, V may increase to uV with probability q or decrease to dV with probability $1 - q$, with $d < 1$,$u > 1$, $d < r < u$, and $r = 1 + r_f$. The up and down factors, u and d, are obtained from the following equations [232]:

$$u = e^{\sigma \sqrt{\Delta T}} \tag{31}$$



(a) Binomial tree of the underlying asset.



(b) Binomial tree of the option value.

Figure 97: Binomial option value model for a simple option (from [26, 232])

$$d = e^{-\sigma\sqrt{\Delta T}} = \frac{1}{u} \tag{32}$$

This process is followed for n time period(s), where $n = T/\Delta T$. In particular it has been shown that as $n \rightarrow \infty$, $\Delta T \rightarrow 0$, and the value of the option provided by the binomial model converges to the one obtained by the Black-Scholes formula. The terminal value C of the option at time T is obtained by com puting the terminal node of the binomial tree of the option value. Hence:

$$C_{uu} = max[0, u^2V - X] \tag{33}$$

$$C_{ud} = max[0, duV - X] \tag{34}$$

$$C_{dd} = max[0, udV - X] \tag{35}$$

where X is the strike price.

By working backward from T to t_0, the value of a preceding node is obtained by setting the risk-neutral probability measure p equal to [232]:

$$p = \frac{e^{r_f} - d}{u - d} \tag{36}$$

and computing:

$$C = \frac{pC_u + (1 - p)C_d}{r} \tag{37}$$

with:

$$C_u = max[0, uV - X] \tag{38}$$

$$C_d = max[0, dV - X] \tag{39}$$

Among the advantages of the binomial model is its transparency and ease of implementation [232]. Because option values are calculated at every step in the binomial tree, the results obtained are easier to explain or validate [26], and can be used with American options to identify early exercise possibilities. Hence, a binomial tree can be used to solve many different types of options, including Nested Options as further discussed below. Among is drawbacks is the number of time steps it requires to reach a good approximation. As such, it is much more computationally intensive than the Black-Scholes formulation.

Based on the descriptions and assumptions of both Black-Scholes and binomial models, the Black-Scholes model is used with Scenarios #2 and #3, while options under Scenario #4 are modeled as sequential compound options (options with multiple phases where the implementation of later phases depends on the success of preceding phases) [232].

7.6 Summary

This chapter presented the last step of the approach introduced in Chapter 3. The following chapter discusses the results obtained by implementing every step of the approach. In particular, it shows how it provides stakeholders with a complete picture of their investment options by enabling both performance and strategic assessments of every portfolios available to them.

CHAPTER VIII

RESULTS AND DISCUSSION

This chapter presents the results for both airport #1(pre-existing equipage) and #2 (little pre-existing equipage) under the four investment scenarios subjected to a "HIGH" change in traffic mix, and a "HIGH" change in the number of arriving aircraft. These results are first discussed for each airport and scenario in the context of their performance. Then, results are further addressed from a more strategic perspective using the Real Options framework introduced in Chapter 7.

8.1 Performance Assessment

Sections 8.1.1, 8.1.2, and 8.1.3 address the performance, at *Airport #1*, of the portfolios considered in Scenarios #2 (investment at Year 5), #3 (investment at Year 10) and #4 (investment at both Years 5 and 10), respectively. Sections 8.1.4, 8.1.5, and 8.1.6 in turn discuss the performance of the portfolios considered at *Airport #2* for the similar investment scenarios. For both airports, results are compared to the corresponding baseline (Scenario #1) across each investment scenarios.

8.1.1 Discussion on Airport #1 Scenario #2

Under Scenario #2 (early investment), investment only occurs at Year 5. In other words, during the first 5 years, the airport operates under its current equipage. The performance of the airport during the 10 following years depends on the technology portfolio considered, as discussed below. As a reminder, the portfolios with their technologies for Scenario #2 are summarized in Table 47. The nomenclature used is the following: $P_{xS_y}k$, where x is the airport number (either 1 or 2), y is the scenario number (either 2, 3 or 4) and k is the portfolio number.

Table 47: *Airport #1* Scenario #2 portfolios and their technologies

Portfolios	Technologies
$P_{1S2}1$	T_{30}
$P_{1S2}2$	T_3
$P_{1S2}3$	T_{29}
$P_{1S2}4$	T_{30}, T_3
$P_{1S2}5$	T_{30}, T_{29}
$P_{1S2}6$	T_3, T_{29}
$P_{1S2}7$	T_{30}, T_3, T_{29}

Figure 98 illustrates the normalized impact of each portfolio on different airport performance metrics during daily operations. In particular, the performance of each portfolio over time is represented by a shade of blue. Hence, the darker the color, the worst the performance of that given portfolio for the metric considered.

A few observations can be made from this figure. First, as expected, different portfolios bring different levels of improvement depending on the performance metric of interest. Hence, Portfolios #4 and #7 appear to have a stronger impact on delays due to runway congestion (highlighted in green in Figure 98) than Portfolios #3 or #5 (highlighted in red in Figure 98), for example. This is consistent with the individual impact of the technologies that composed these portfolios. In particular, Figure 99 helps to quickly identify portfolios that perform best across most of the metrics considered. By examining the portfolios having the lightest color after Year 5, one is able to rapidly determine the ones that may provide a "universal solution" to airports. The identification of such portfolios is further facilitated by the parallel plot provided in Figure 100, which illustrates how each portfolio performs at Year 15. The desired portfolios are the ones that minimize delays and utilization ratios, but maximize departure and arrival capacities, as noted by the arrows in Figures 100(a) and 100(b). This figure reinforces the previous observation that, for this airport and scenario, no unique portfolio provides the most benefit to all metrics. However, it illustrates that Portfolios #4 and #7 perform the best in 8 out of the 11 metrics considered.

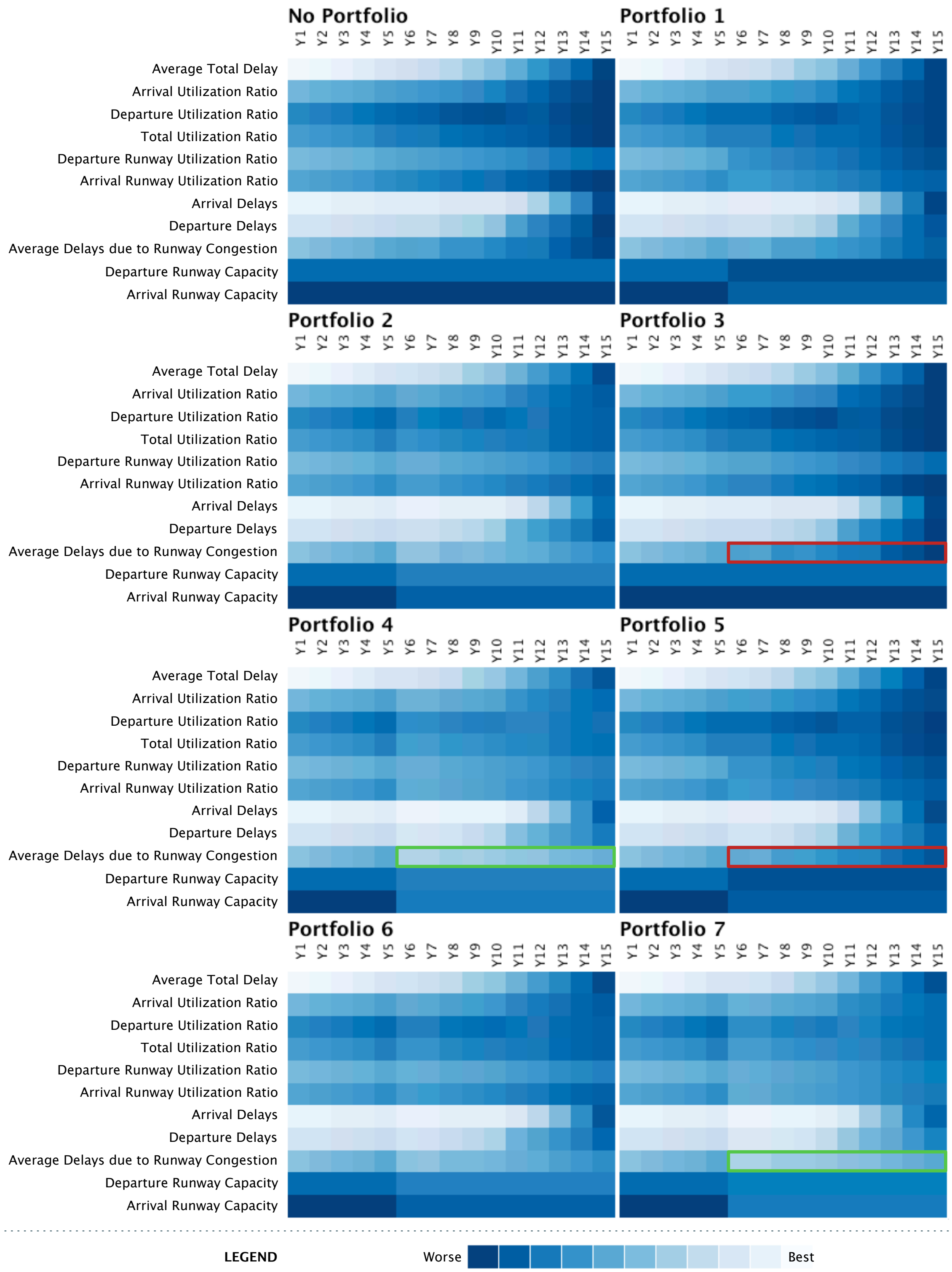


Figure 98: Performance of all portfolios across all performance metrics for *Airport #1* Scenario #2.

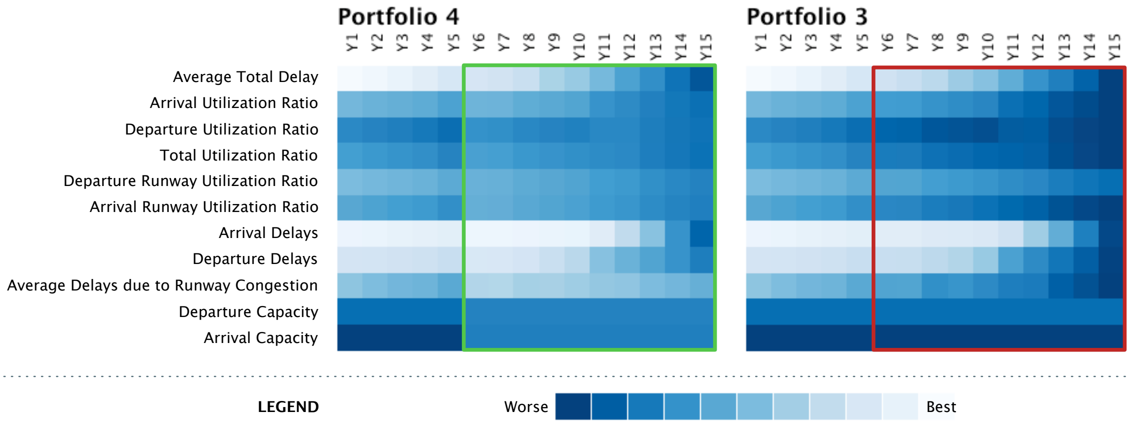
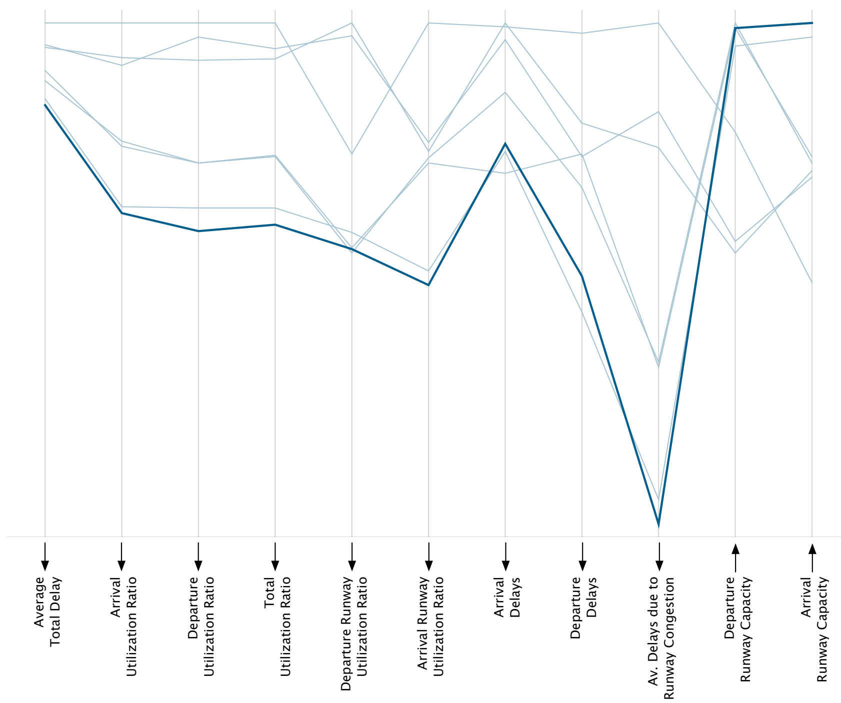


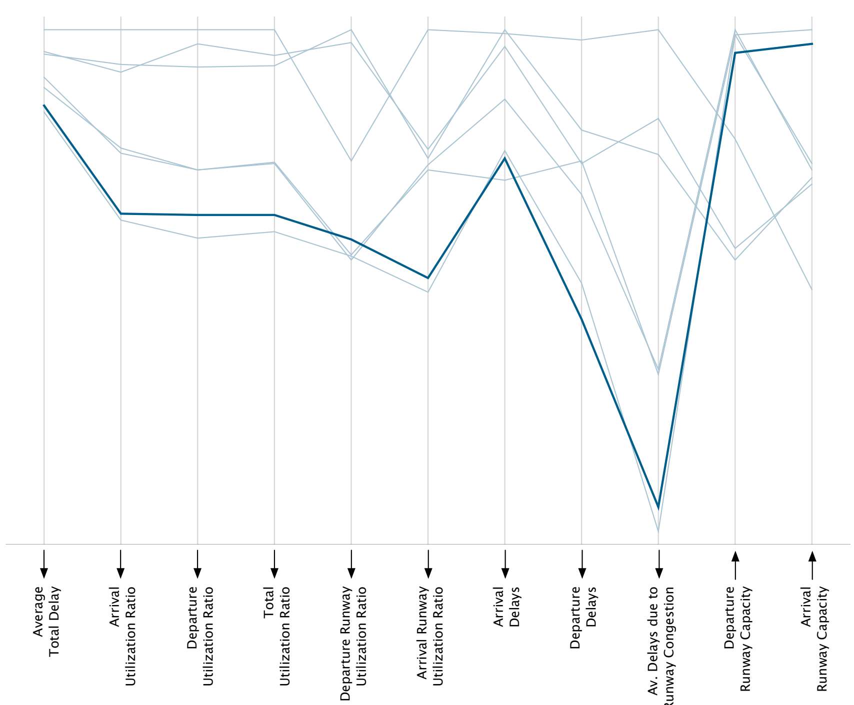
Figure 99: Rapid performance comparison between Portfolios #3 and #4 (Scenario #2).

Figure 100, along with Figure 101, also help identify groupings of portfolios, in other words, portfolios that perform similarly on a given response. For example, Figure 101 shows that the following portfolio groupings 1/5, 2/6, and 4/7 can be considered when looking at improvements to the average delay due to runway congestion. Such information, as discussed in Section 8.2, can eventually assist the decision maker in choosing the most cost-effective portfolio between portfolios having similar impacts.

Finally, Figure 102 represents variations in performance across all portfolios, with the darkest color being synonym to worst performance. This figure helps rapidly distinguish and compare the degree of improvement brought by each portfolio. Most importantly, it allows the analyst to identify potential unsolved issues such as the one where the average total delay keeps increasing despite an increase in both arrival and departure capacities and a decrease in the average delay due to runway congestion. This situation is further addressed in Section 8.1.4.



(a) Scenario #2 portfolio #4 performance.



(b) Scenario #2 portfolio #7 performance.

Figure 100: Performance of the two best portfolios under Scenario #2 at Year 15.

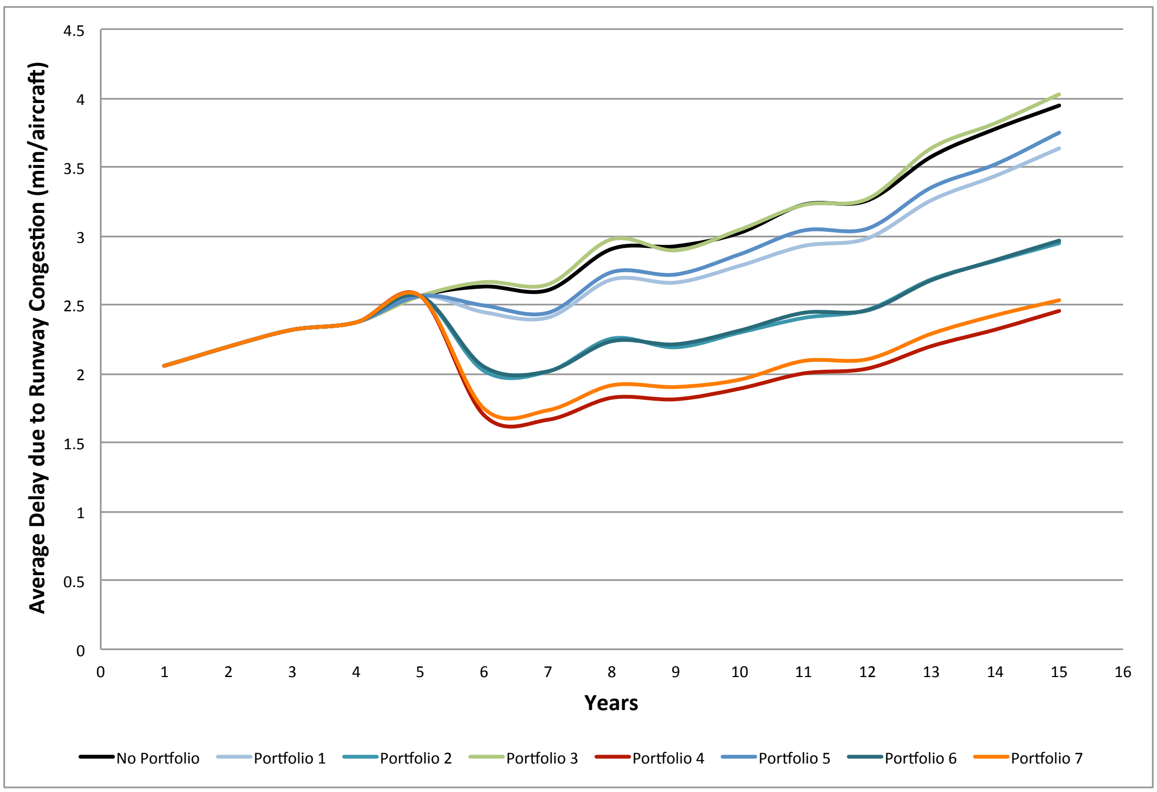


Figure 101: Average delay due to runway congestion over time for all portfolios considered under Scenario #2.

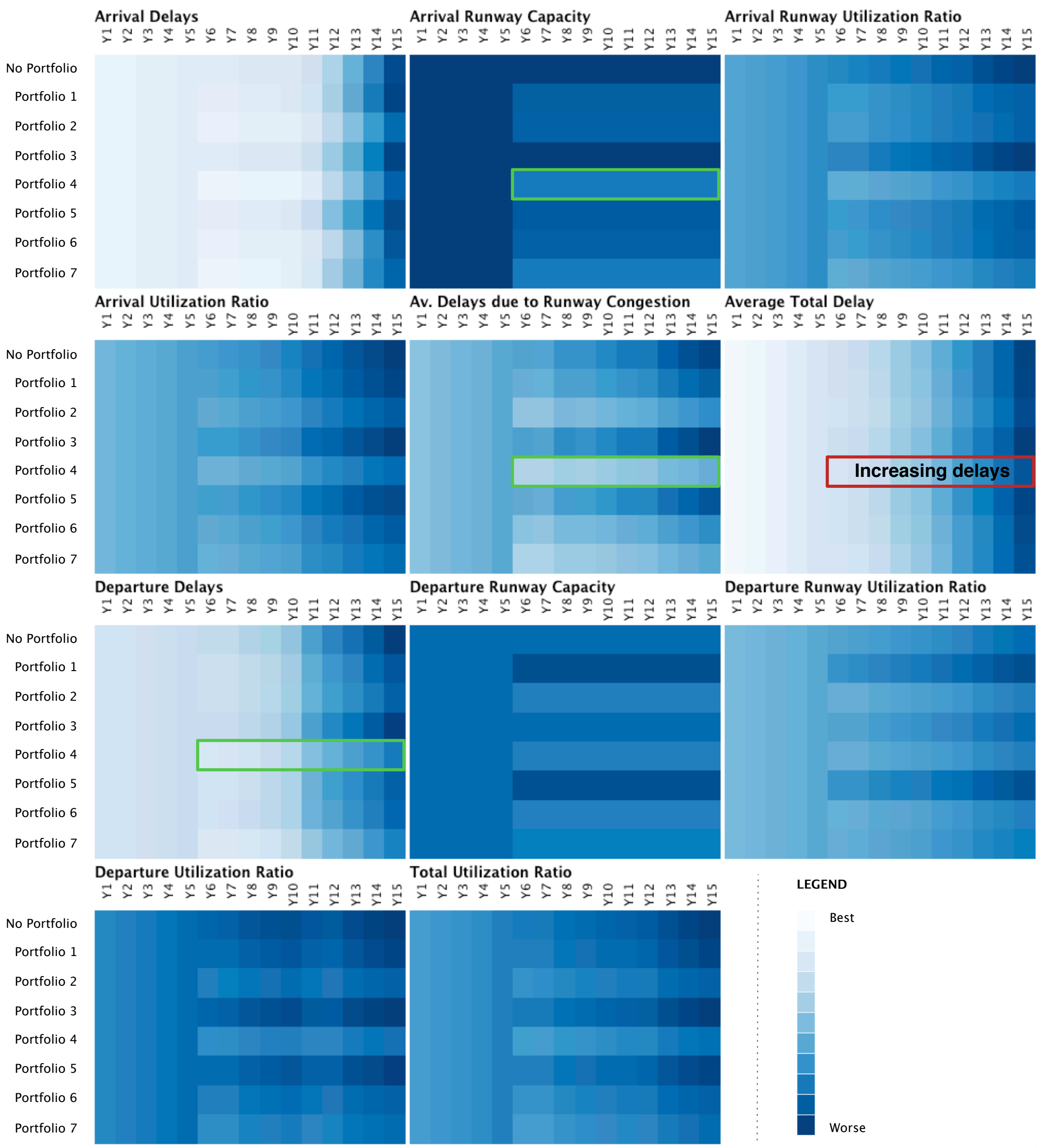


Figure 102: Variations in performance across all *Airport #1* Scenario #2 portfolios.

8.1.2 Discussion on Airport #1 Scenario #3

Under Scenario #3 (late investment), investment only occurs at Year 10. In other words, during the first 10 years, the airport operates under its current equipage. The performance of the airport during the last 5 years depends on the technology portfolio considered, as discussed below. As a reminder, the portfolios with their technologies for Scenario #3 are summarized in Table 48.

Table 48: *Airport #1* Scenario #3 portfolios and their technologies

Portfolios	**Technologies**
$P_{1S3}1$	T_{30}
$P_{1S3}2$	T_{28}
$P_{1S3}3$	T_{3}
$P_{1S3}4$	T_{29}
$P_{1S3}5$	T_{30}, T_{28}
$P_{1S3}6$	T_{30}, T_{3}
$P_{1S3}7$	T_{30}, T_{29}
$P_{1S3}8$	T_{28}, T_{3}
$P_{1S3}9$	T_{28}, T_{29}
$P_{1S3}10$	T_{3}, T_{29}
$P_{1S3}11$	T_{30}, T_{28}, T_{3}
$P_{1S3}12$	T_{30}, T_{28}, T_{29}
$P_{1S3}13$	T_{30}, T_{3}, T_{29}
$P_{1S3}14$	T_{28}, T_{3}, T_{29}
$P_{1S3}15$	T_{30}, T_{28}, T_{3}, T_{29}

Similar to Figure 98, Figure 105 helps identify portfolios that perform best across most of the metrics of interest over time. The parallel chart provided in Figure 104 reveals that at Year 15, Portfolios #11 and #15 perform the best in all of the 11 metrics considered.

Finally, Figure 105 reinforces the observation made in Section 8.1.1 that the average total delay keeps increasing despite a significant decrease in departure and arrival runway utilization ratios, total utilization ratios and delays due to runway congestion, and an increase in both arrival and departure capacities (Portfolio #11).

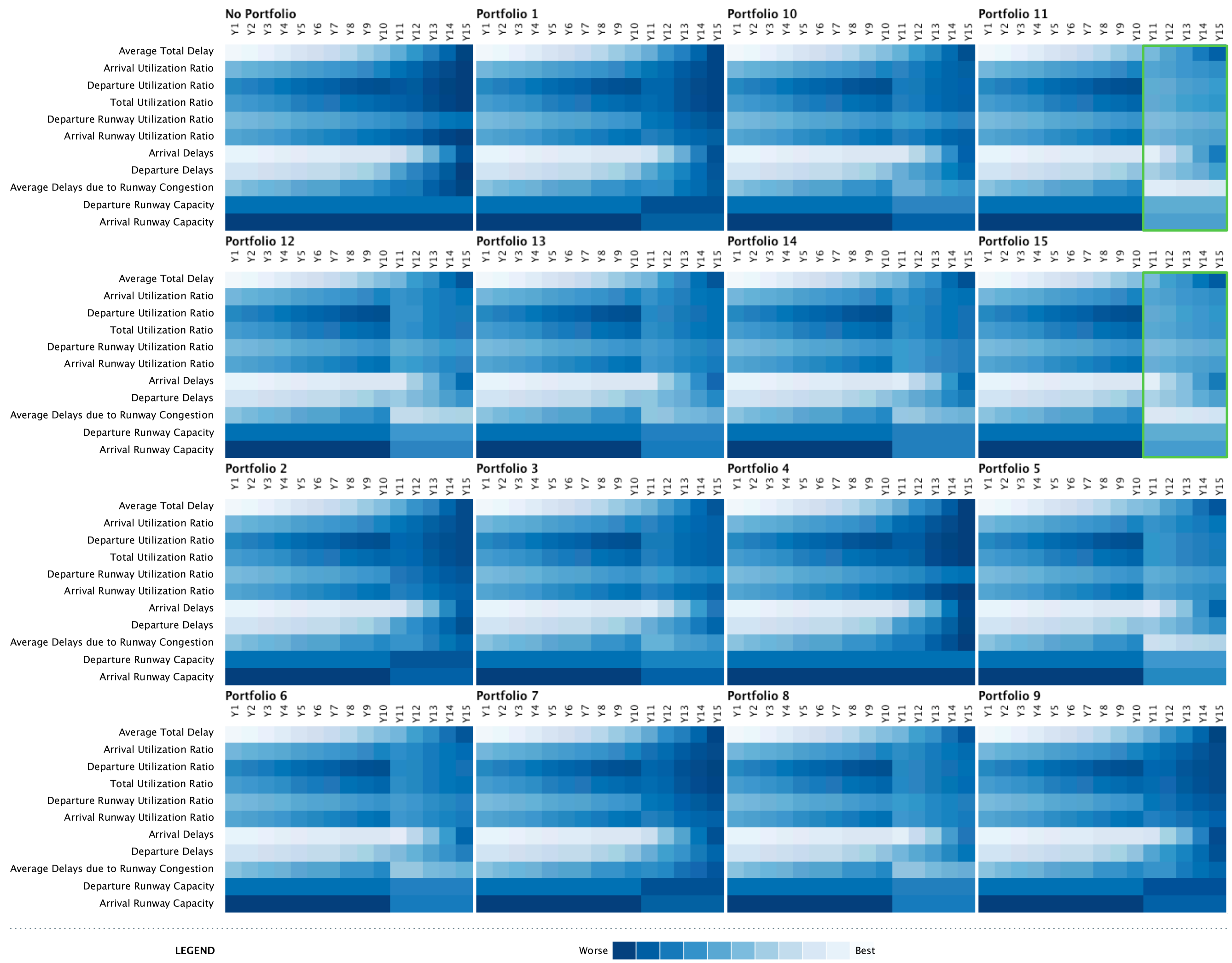
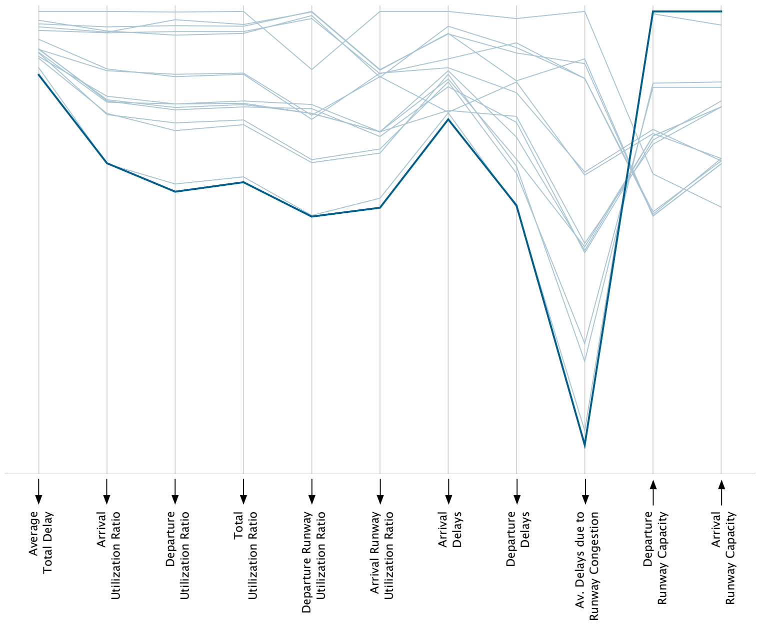
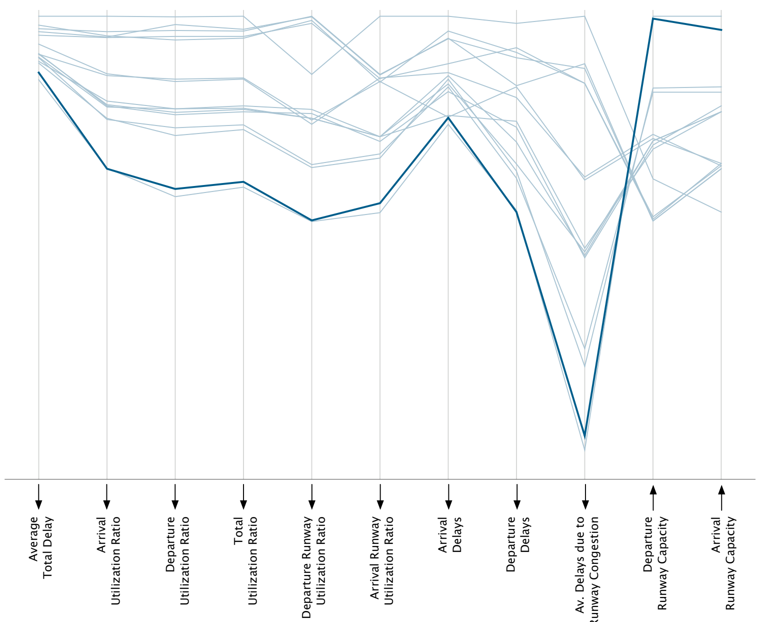


Figure 103: Performance of all portfolios across all performance metrics for *Airport #1* Scenario #3.



(a) Scenario #3 portfolio #11 performance.



(b) Scenario #3 portfolio #15 performance.

Figure 104: Performance of the two best portfolios under Scenario #3 at Year 15.

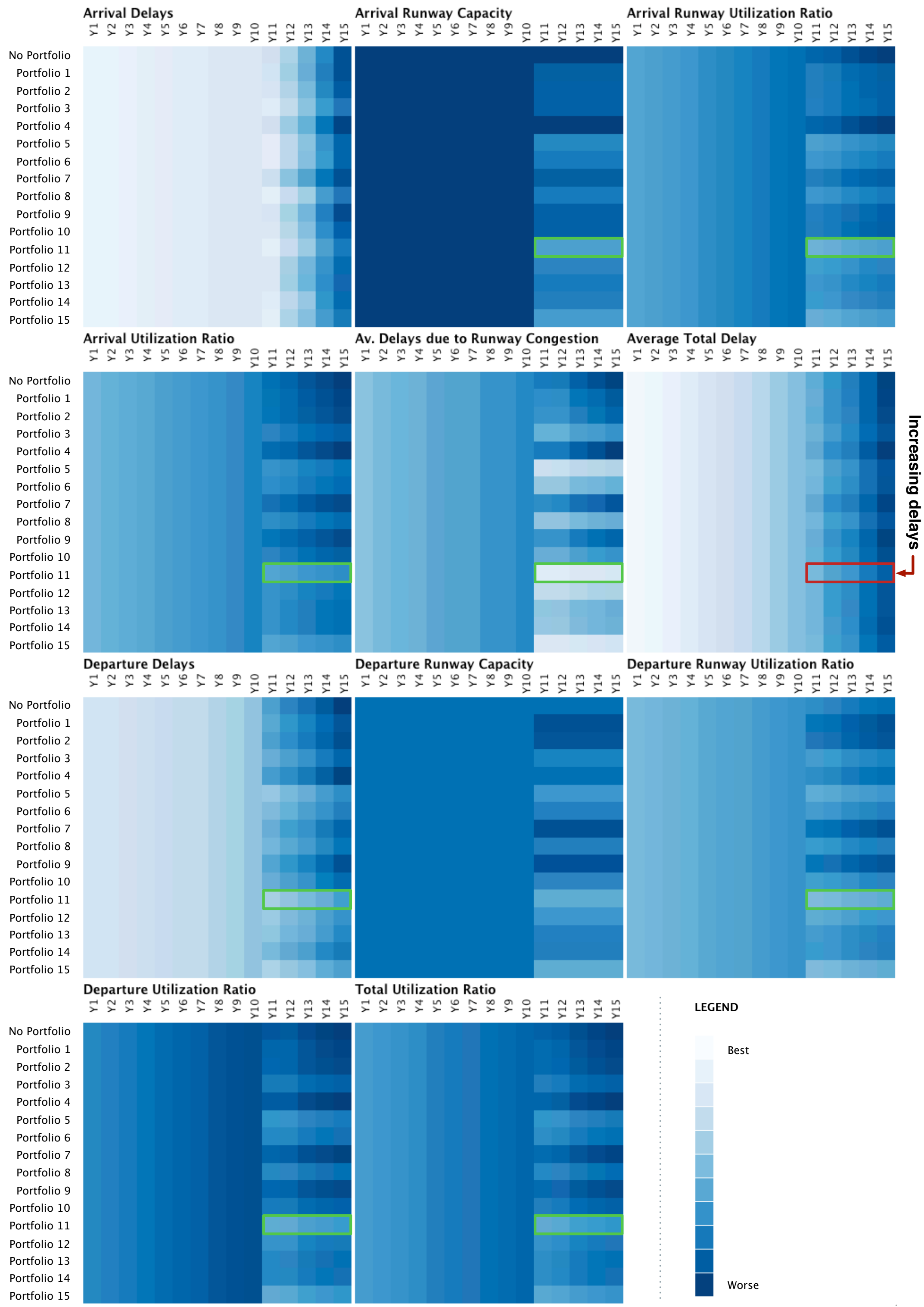


Figure 105: Variations in performance across all *Airport #1* Scenario #3 portfolios.

8.1.3 Discussion on Airport #1 Scenario #4 and Observations on Airport #1 Investment Scenarios

Under Scenario #4 (sequential investment), investment occurs at both Years 5 and 10. During the first 5 years, the airport operates under its current equipage. During the following 5 years, it operates with any of the portfolios available during Scenario #2. At the end of these 10 years, the airport complements that portfolio with any of the portfolios from Scenario #3 that include the technologies present from Year 5 to Year 10. All the potential combinations of portfolios for both 5-year time frames are summarized in Table 49.

Figure 106 illustrates the evolution of the various delay related responses over time for each scenario (Scenario #1: no portfolio - baseline, Scenario #2: investment at Year 5, Scenario #3: investment at Year 10, Scenario #4: investment at both Year 5 and Year 10). In particular, this figure evidences the difference between each scenario by comparing the average in performance at each year.

8.1.3.1 Average Total Delays

Figure 106 shows that Scenario #4 portfolios perform better, on average, after Year 11, than any other portfolios. Also, as expected, Scenario #2 (early investment) provides more improvements between Years 5 and 10 than any other scenarios. However, this trend is slowly reverted once Scenario #3 portfolios are introduced. Finally, the difference in performance between Scenarios #2 and #3 after Year 11 appears to be more important than between Scenarios #3 (late investment) and #4 (sequential investment). This information is, however, of little value since there is no option to go from investment scenario #2 to investment scenario #3. Indeed, Scenarios #2 and #3 can only be "upgraded" to Scenario #4.

8.1.3.2 Average Delays due to Runway Congestion

As illustrated in Figure 106 (top right corner), the variability in the performance of the portfolios considered in Scenarios #3 and #4 is particularly significant, more so than for

Table 49: Scenario #4 portfolios and their technologies

Portfolios	**Tech. from Year 5 to Year 10**	**Tech. from Year 10 to Year 15**
$P_{1S4}1$	T_{30}	T_{30}, T_{28}
$P_{1S4}2$	T_{30}	T_{30}, T_{3}
$P_{1S4}3$	T_{30}	T_{30}, T_{29}
$P_{1S4}4$	T_{30}	T_{30}, T_{28}, T_{3}
$P_{1S4}5$	T_{30}	T_{30}, T_{28}, T_{29}
$P_{1S4}6$	T_{30}	T_{30}, T_{3}, T_{29}
$P_{1S4}7$	T_{30}	T_{30}, T_{28}, T_{3}, T_{29}
$P_{1S4}8$	T_{3}	T_{30}, T_{3}
$P_{1S4}9$	T_{3}	T_{28}, T_{3}
$P_{1S4}10$	T_{3}	T_{3}, T_{29}
$P_{1S4}11$	T_{3}	T_{30}, T_{28}, T_{3}
$P_{1S4}12$	T_{3}	T_{30}, T_{3}, T_{29}
$P_{1S4}13$	T_{3}	T_{28}, T_{3}, T_{29}
$P_{1S4}14$	T_{3}	T_{30}, T_{28}, T_{3}, T_{29}
$P_{1S4}15$	T_{29}	T_{30}, T_{29}
$P_{1S4}16$	T_{29}	T_{28}, T_{29}
$P_{1S4}17$	T_{29}	T_{3}, T_{29}
$P_{1S4}18$	T_{29}	T_{30}, T_{28}, T_{29}
$P_{1S4}19$	T_{29}	T_{30}, T_{3}, T_{29}
$P_{1S4}20$	T_{29}	T_{28}, T_{3}, T_{29}
$P_{1S4}21$	T_{29}	T_{30}, T_{28}, T_{3}, T_{29}
$P_{1S4}22$	T_{30}, T_{3}	T_{30}, T_{28}, T_{3}
$P_{1S4}23$	T_{30}, T_{3}	T_{30}, T_{3}, T_{29}
$P_{1S4}24$	T_{30}, T_{3}	T_{30}, T_{28}, T_{3}, T_{29}
$P_{1S4}25$	T_{30}, T_{29}	T_{30}, T_{28}, T_{29}
$P_{1S4}26$	T_{30}, T_{29}	T_{30}, T_{3}, T_{29}
$P_{1S4}27$	T_{30}, T_{29}	T_{30}, T_{28}, T_{3}, T_{29}
$P_{1S4}28$	T_{3}, T_{29}	T_{30}, T_{3}, T_{29}
$P_{1S4}29$	T_{3}, T_{29}	T_{28}, T_{3}, T_{29}
$P_{1S4}30$	T_{3}, T_{29}	T_{30}, T_{28}, T_{3}, T_{29}
$P_{1S4}31$	T_{30}, T_{3}, T_{29}	T_{30}, T_{28}, T_{3}, T_{29}

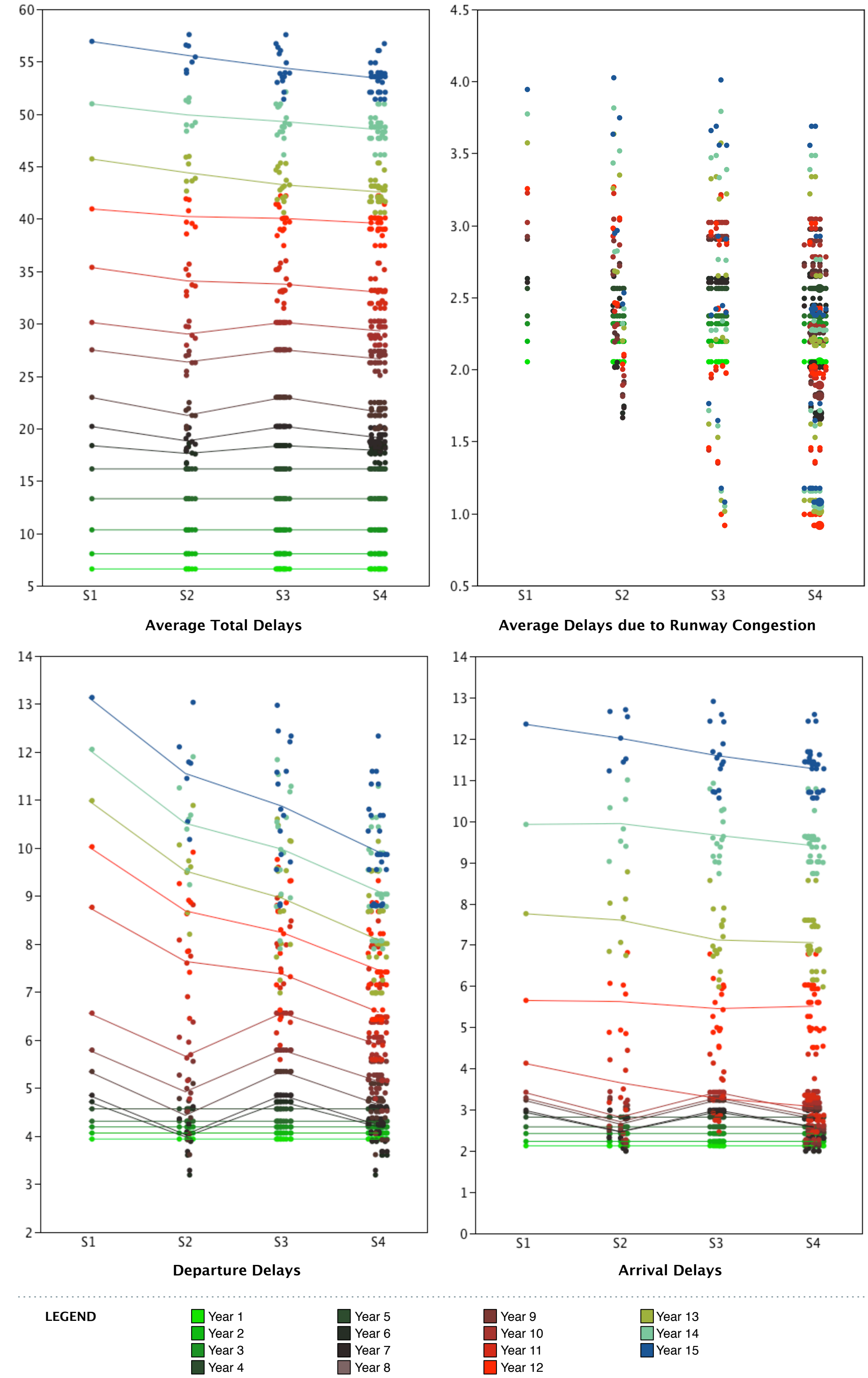
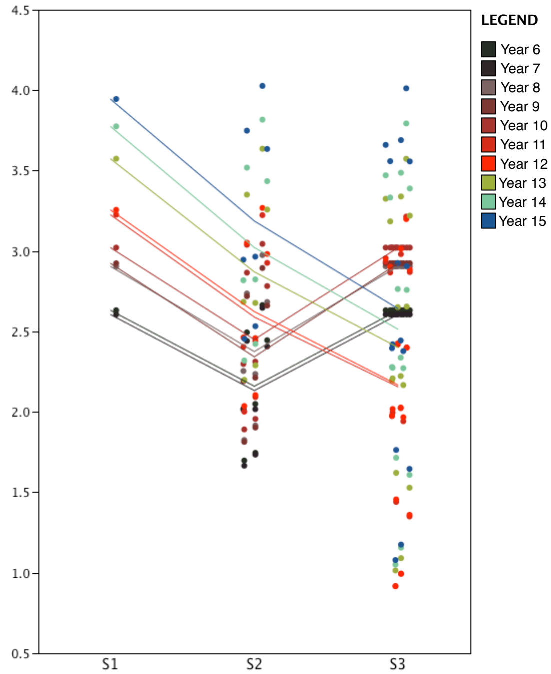
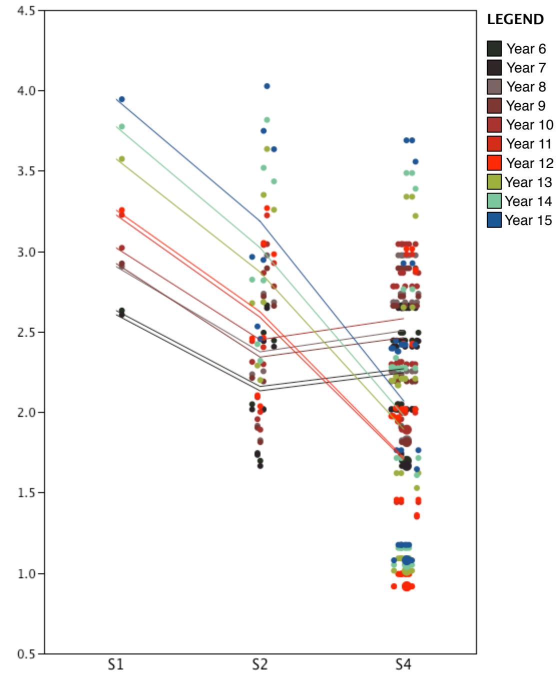


Figure 106: Delays (min/aircraft) for Scenarios #1, #2, #3, and #4 (S1, S2, S3, S4).

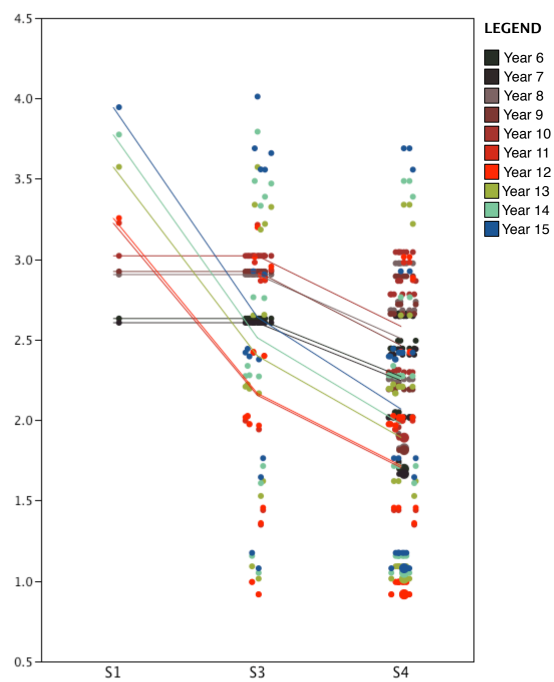
Scenario #2. Figure 107(a) shows that, on average, Scenario #2 understandably exhibits lower delays due to runway congestion than Scenario #3 between the Years 6 and 10. Scenario #3 eventually leads to the lowest level of delays at Year 15. Hence, choosing between Scenarios #2 (early investment) and #3 (late investment) should be based upon the time frame considered and the ability of the airport to operate under higher levels of delays during Year 6 to Year 10. Also, when comparing Figures 107(a) with 107(b), one can observe that the difference in the average performance, between the years 6 and 10, of Scenarios #2 and #3 is more important than the one between Scenarios #2 and #4. However, this trend changes after Year 10, with the average benefit of Scenario #4 over Scenario #2 surpassing the one of Scenario #3 over Scenario #2. Hence, given the timeframe considered (15 years), pursuing an earlier investment over a later one seems preferable. Doing so also offers the possibility for the decision-maker to later invest in additional technologies (i.e. pursue Scenario #4 (sequential investment). The small difference in the average performance, from Year 6 to Year 10, between Scenarios #2 and #4 can be explained by the number and nature of the portfolios considered during that period. 1-technology portfolios under Scenario #2 lead to more Scenario #4 portfolios than 2-technology portfolios. Indeed, given a limited number of technologies to choose from, a 1-technology portfolio under Scenario #2 could result in 7 portfolios under Scenario #4 (see Table 49), while a (better performing) 2-technology portfolio under Scenario #2 would only lead to 3 portfolios under Scenario #4. This consequently lowers the average performance of Scenario #4 for the years 6 to 10, as illustrated in Figure 107(b). Figure 107(c) shows that, on average, Scenario #4 leads to fewer delays due to runway congestion than Scenario #3 for the entire timeframe considered. Finally, it is important to note that the variability in the performance of Scenario #4 portfolios is significant. Consequently, when following Scenario #4, selection of the portfolio must take into account this uncertainty, as there exists many portfolios under this scenario that perform worse than some under Scenario #2 or #3. In other words, deciding to follow Scenario #4 does not automatically result in increased performance.



(a) Between Scenarios #1, #2 and #3.



(b) Between Scenarios #1, #2 and #4.



(c) Between Scenarios #1, #3 and #4.

Figure 107: Comparison of average delays (min/aircraft) due to runway congestion between each scenarios for Years 6 to 15.

8.1.3.3 Departure and Arrival Delays

Figure 106 (bottom) shows that Scenario #4 provides, on average, a more significant decrease in departure delays than in arrival delays when compared to Scenarios #1, #2 and #3 at Year 15. However, the variability in the portfolio performance is much more important for departure delays than it is for arrival delays. Also, as expected, the difference between each scenario depends on the time-frame considered. Hence, at Year 12, the difference in arrival delays across all scenarios is much less significant than at Year 15. Also, the improvement in arrival delays between Scenarios #2 and #3 after Year 11 appears to be more important than between Scenarios #3 and #4. Finally, while understandably Scenario #2 performs better between Years 5 and 10 in terms of departure delays, this trend is quickly reverted once Scenario #3 portfolios are introduced.

Figure 108 illustrates the best portfolios under each scenario at Year 15 across all the responses considered. Table 50 complements Figure 108 by enumerating the technologies that constitute these portfolios, and by further summarizing the improvement they bring to each individual response.

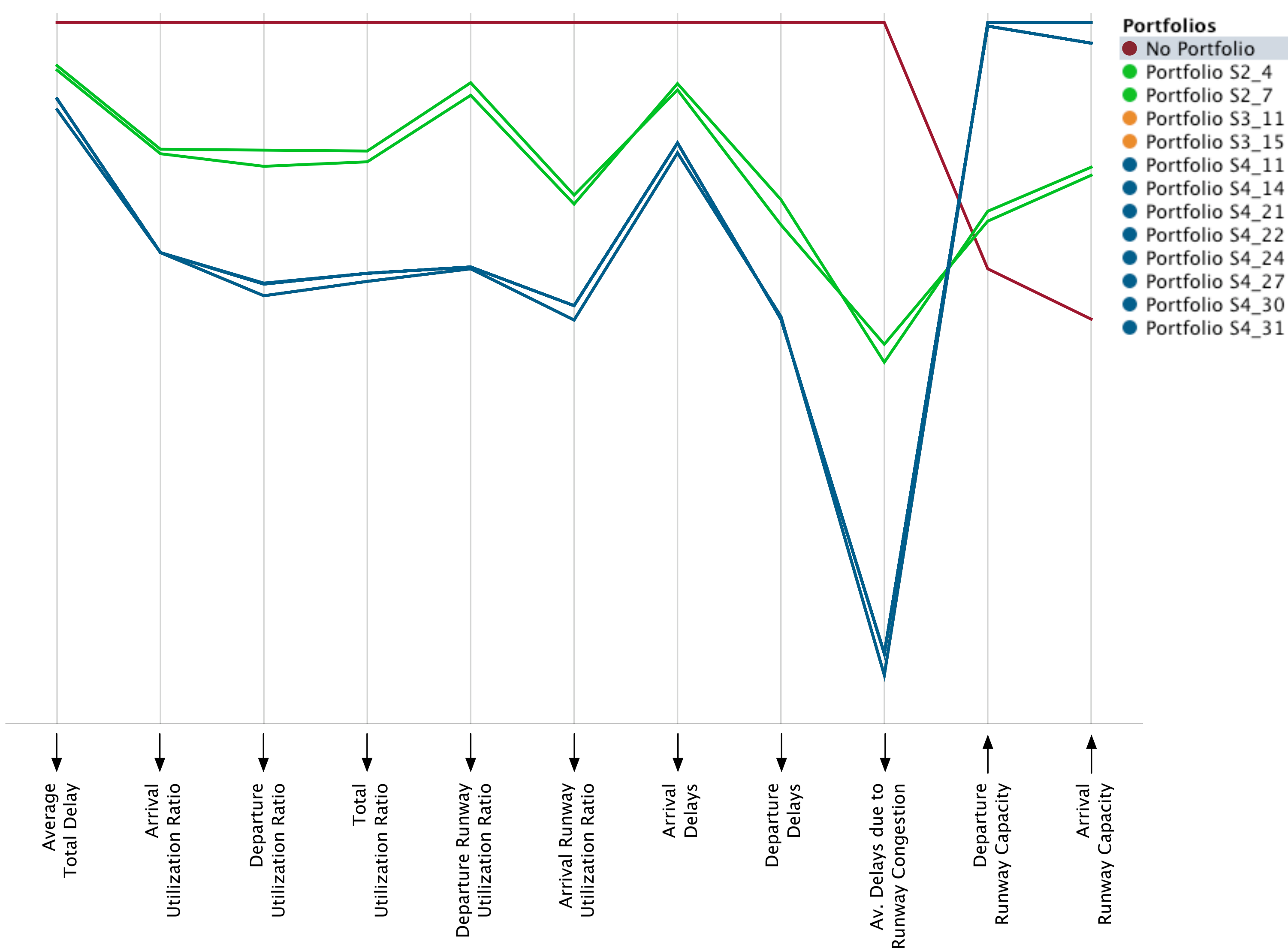


Figure 108: Comparison of the best portfolios performance for all four scenarios at Year15 (blue and orange lines are superimposed).

Table 50: Best portfolios and their corresponding technologies at Year 15 for all responses and scenarios (*Airport #1*)

Responses	Scenarios	Technologies	Impr. from baseline
Average total delay	S1	-	-
	S2	$P_{1S2}4$: T_{30}, T_3	5.305%
	S3	$P_{1S3}11$: T_{30}, T_{28}, T_3	9.698%
	S4*	T_{30}, T_{28}, T_3	9.698%
Arrival utilization ratio	S1	-	-
	S2	$P_{1S2}4$: T_{30}, T_3	14.599%
	S3	$P_{1S3}15$: T_{30}, T_{28}, T_3, T_{29}	25.593%
	S4*	T_{30}, T_{28}, T_3, T_{29}	25.593%
Departure utilization ratio	S1	-	-
	S2	$P_{1S2}4$: T_{30}, T_3	15.985%
	S3	$P_{1S3}11$: T_{30}, T_{28}, T_3	30.439%
	S4*	T_{30}, T_{28}, T_3	30.439%
Total utilization ratio	S1	-	-
	S2	$P_{1S2}4$: T_{30}, T_3	15.516%
	S3	$P_{1S3}11$: T_{30}, T_{28}, T_3	28.811%
	S4*	T_{30}, T_{28}, T_3	28.811%
Departure runway utilization ratio	S1	-	-
	S2	$P_{1S2}5$: T_{30}, T_{29}	8.431%
	S3	$P_{1S3}11$: T_{30}, T_{28}, T_3	27.431%
	S4*	T_{30}, T_{28}, T_3	27.431%
Arrival runway utilization ratio	S1	-	-
	S2	$P_{1S2}4$: T_{30}, T_3	20.231%
	S3	$P_{1S3}11$: T_{30}, T_{28}, T_3	33.054%
	S4*	T_{30}, T_{28}, T_3	33.054%
Arrival delays	S1	-	-
	S2	$P_{1S2}2$: T_3	9.199%
	S3	$P_{1S3}11$: T_{30}, T_{28}, T_3	14.517%
	S4*	T_{30}, T_{28}, T_3	14,517%
Departure delays	S1	-	-
	S2	$P_{1S2}7$: T_{30}, T_3, T_{29}	22.509%
	S3	$P_{1S3}15$: T_{30}, T_{28}, T_3, T_{29}	33.067%
	S4*	T_{30}, T_{28}, T_3, T_{29}	33.067 %
Av. delays due to runway congestion	S1	-	-
	S2	$P_{1S2}4$: T_{30}, T_3	37.771%
	S3	$P_{1S3}11$: T_{30}, T_{28}, T_3	72.647%
	S4*	T_{30}, T_{28}, T_3	72.647%
Departure runway capacity	S1	-	-
	S2	$P_{1S2}2$: T_3, T_{29}	9.314%
	S3	$P_{1S3}11$: T_{30}, T_{28}, T_3	37.745%
	S4*	T_{30}, T_{28}, T_3	37.745%
Arrival runway capacity	S1	-	-
	S2	$P_{1S2}4$: T_{30}, T_3	25.343%
	S3	$P_{1S3}11$: T_{30}, T_{28}, T_3	49.315%
	S4*	T_{30}, T_{28}, T_3	49.315%

* Multiple portfolios

8.1.3.4 Technology Ranking

The technology ranking presented in Figure 110 is obtained by allocating scores for each scenario and each response at Y15 according to the following:

- A score of 5 for technologies belonging to the best portfolio
- A score of 3 for the technologies belonging to the second best portfolio
- A score of 1 for the technologies belonging to the third best portfolio

The scores are then summed up across the entire set of responses for any given scenario. The technologies considered are listed in Table 51.

Table 51: Technologies considered for future investment options at airport #1

ID	Technology Name
T_3	Multilateration (MLAT)
T_{28}	Departure MANager (DMAN)
T_{29}	Surface MANager (SMAN)
T_{30}	Arrival MANager (AMAN)

In particular, Figure 109 illustrates that the combination T_{30}/T_{28} (AMAN/DMAN) seems to perform better, under this set of assumptions and conditions, than the combination T_{30}/T_{29} (AMAN/SMAN). Hence, if one were to consider pursuing investment scenario #4, investing in technologies T_{30} and T_3 for the period Y6-Y10 and then complementing that portfolio with technology T_{28} for the period Y11-Y15 would appear as a good approach.

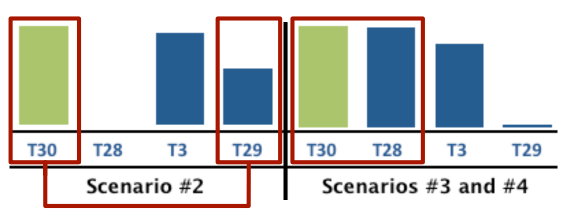


Figure 109: Comparison between T_{30}/T_{29} and T_{30}/T_{28} for *Airport #1* scenarios at Y15.

Figure 110: Technology ranking across *Airport #1* scenarios at Y15.

8.1.4 Discussion on Airport #2 Scenario #2

Similar to *Airport #1*, investments under Scenario #2 for *Airport #2* only occur at Year 5. As described in Section 7.4, the baseline for *Airport #2* does not include any lighting system. This forces this airport to operate under a different schedule where flights can not take off or land after 5pm. This translates into a decrease of 38.49% and 48.85% of the number of small and medium aircraft arriving, respectively. It also reduces the number of operating hours at the airport from 18 to 11 hours. All this, as further discussed below, has an impact on the performance and attractiveness of the technologies considered. The portfolios and their respective technologies for Scenario #2 are listed in Table 52.

The following section first discusses the performance of portfolios that do not include lighting technology (T_{21}). It then explores the impact that such technology has on the level of traffic at the airport, and further illustrates and discusses the extent to which new ground technologies can address delay at the airport.

8.1.4.1 Scenario #2 with no Lighting Technology

Under such scenario, the airport accommodates from 68 (at Year 1) to 104 (at Year 15) daily operations. Figure 111 illustrates the evolution of the average total delay (min/aircraft) during this period, as well as the benefit provided by each of the portfolios from Table 52 that do not include T_{21}. In particular, it shows that the average total delay for the baseline (black line) over the years may not reach a level that requires the deployment of new technologies. In other words, under the conditions, scenario and assumptions considered, the absence of lighting technology at the airport does not necessitate investment in additional technologies.

Finally, Figure 112 illustrates the difficulty to identify a key portfolio (one that performs best across all the responses of interest) for this scenario.

Table 52: Airport #2 Scenario #2 portfolios and their technologies

Portfolios	Technologies	Observations
$P_{2S2}1$	T_{30}	No flights after dark
$P_{2S2}2$	T_{21}	
$P_{2S2}3$	T_{5}	No flights after dark
$P_{2S2}4$	T_{3}	No flights after dark
$P_{2S2}5$	T_{29}	No flights after dark
$P_{2S2}6$	T_{30}, T_{21}	
$P_{2S2}7$	T_{30}, T_{5}	No flights after dark
$P_{2S2}8$	T_{30}, T_{3}	No flights after dark
$P_{2S2}9$	T_{30}, T_{29}	No flights after dark
$P_{2S2}10$	T_{21}, T_{5}	
$P_{2S2}11$	T_{21}, T_{3}	
$P_{2S2}12$	T_{21}, T_{29}	
$P_{2S2}13$	T_{5}, T_{3}	No flights after dark
$P_{2S2}14$	T_{5}, T_{29}	No flights after dark
$P_{2S2}15$	T_{3}, T_{29}	No flights after dark
$P_{2S2}16$	T_{30}, T_{21}, T_{5}	
$P_{2S2}17$	T_{30}, T_{21}, T_{3}	
$P_{2S2}18$	T_{30}, T_{21}, T_{29}	
$P_{2S2}19$	T_{30}, T_{5}, T_{3}	No flights after dark
$P_{2S2}20$	T_{30}, T_{5}, T_{29}	No flights after dark
$P_{2S2}21$	T_{30}, T_{3}, T_{29}	No flights after dark
$P_{2S2}22$	T_{21}, T_{5}, T_{3}	
$P_{2S2}23$	T_{21}, T_{5}, T_{29}	
$P_{2S2}24$	T_{21}, T_{3}, T_{29}	
$P_{2S2}25$	T_{5}, T_{3}, T_{29}	No flights after dark
$P_{2S2}26$	T_{30}, T_{21}, T_{5}, T_{3}	
$P_{2S2}27$	T_{30}, T_{21}, T_{5}, T_{29}	
$P_{2S2}28$	T_{30}, T_{21}, T_{3}, T_{29}	
$P_{2S2}29$	T_{30}, T_{5}, T_{3}, T_{29}	No flights after dark
$P_{2S2}30$	T_{21}, T_{5}, T_{3}, T_{29}	
$P_{2S2}31$	T_{30}, T_{21}, T_{5}, T_{3}, T_{29}	

8.1.4.2 Scenario #2 with Lighting Technology

The introduction of lighting technology at Year 6, which allows aircraft to operate after 5pm, has a direct impact on the number of operations the airport needs to accommodate. The resulting jump in traffic is pictured in Figure 113.

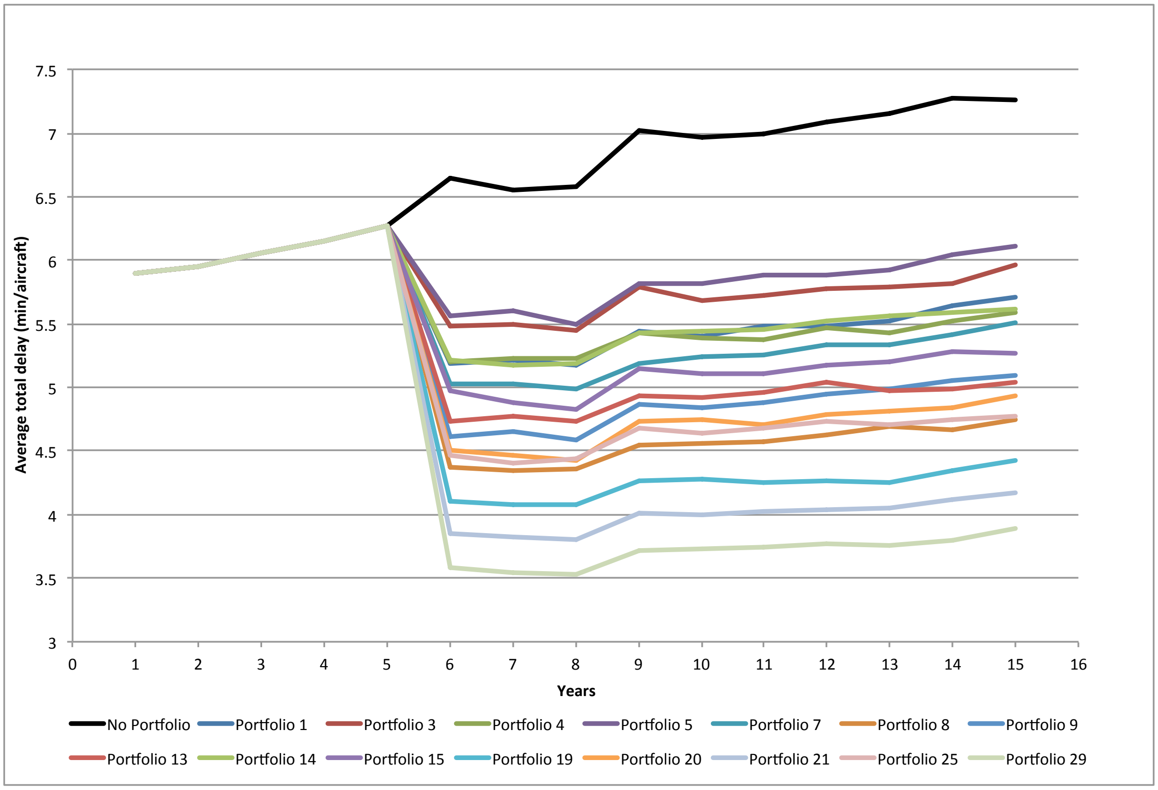
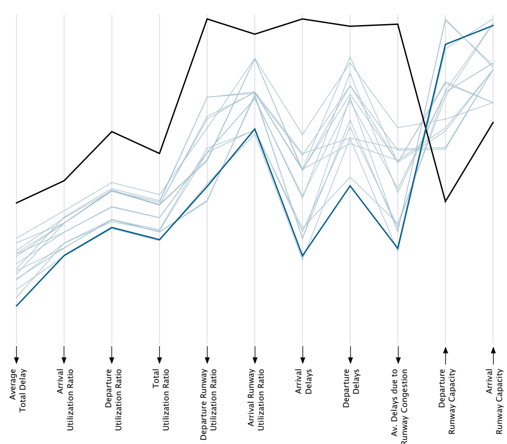
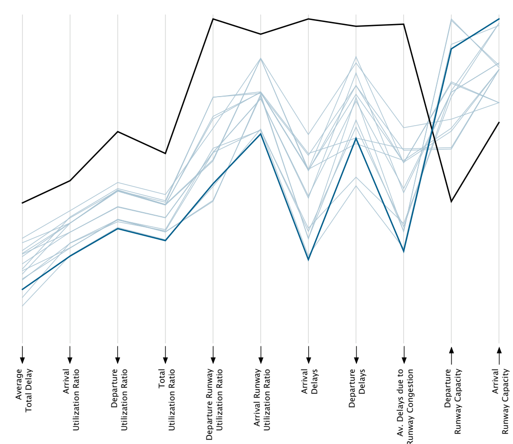


Figure 111: Average total delays (min/aircraft) for all Scenario #2 portfolios with no lighting technology at *Airport #2*.



(a) Scenario #2 portfolio #29 performance (baseline in black).



(b) Scenario #2 portfolio #19 performance (baseline in black).

Figure 112: Performance of promising portfolios without lighting technology (in blue) under Scenario #2 at Year 15.

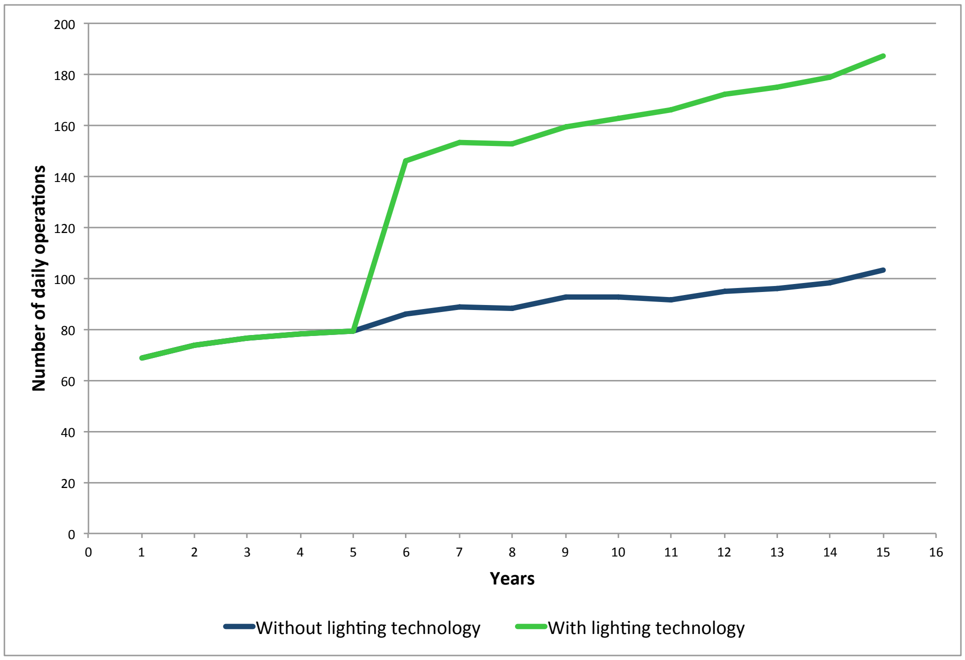
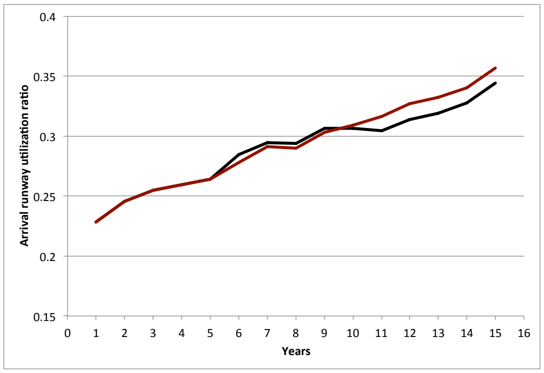


Figure 113: Growth in daily operations at *Airport #2 with and without lighting technology.*

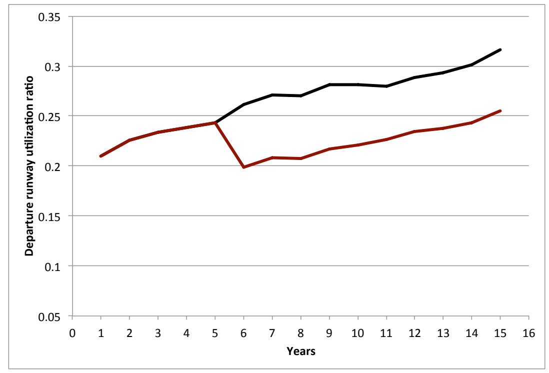
The impact of solely adding lighting technology to the airport (Portfolio #2) is further illustrated in Figures 114 and 115 for all the responses of interest. In particular, it shows that, despite the relative improvement (or limited degradation) in departure and arrival runway utilization ratios (Figures 114(b) and 114(a), respectively), both departure and arrival utilization ratios (at the airside level) increase significantly (Figures 114(d) and 114(c)). Those ratios, discussed in Section 6.2.3.2 and defined again below (Equations 40 and 41), indicate that the number of departures and arrivals increase faster than the departure and arrival capacities of the airport.

$$\rho_{\text{AirsideDep}} = \frac{\text{Number of departures}}{\text{Total departure capacity}} \tag{40}$$

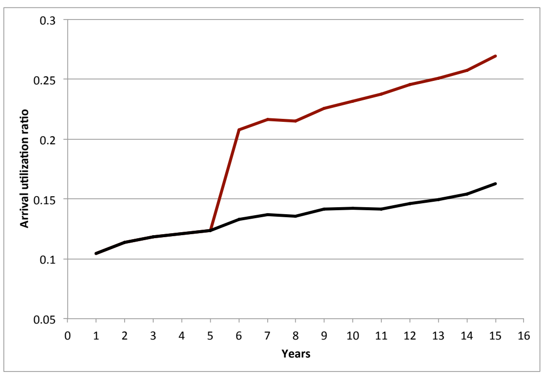
$$\rho_{\text{AirsideArr}} = \frac{\text{Number of arrivals}}{\text{Total arrival capacity}} \tag{41}$$



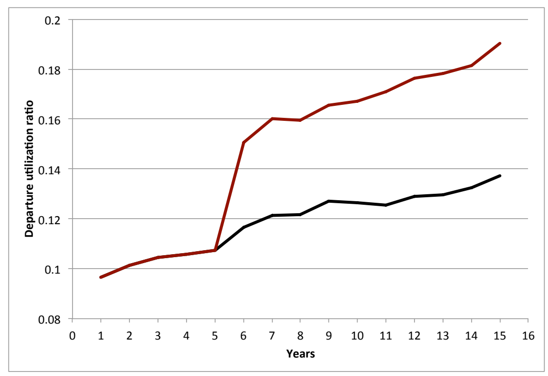
(a) Arrival runway utilization ratio.



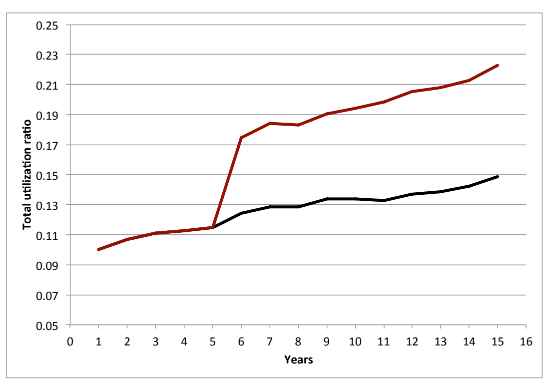
(b) Departure runway utilization ratio.



(c) Arrival utilization ratio.

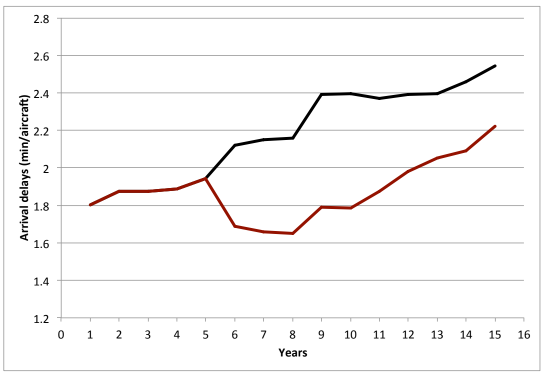


(d) Departure utilization ratio.

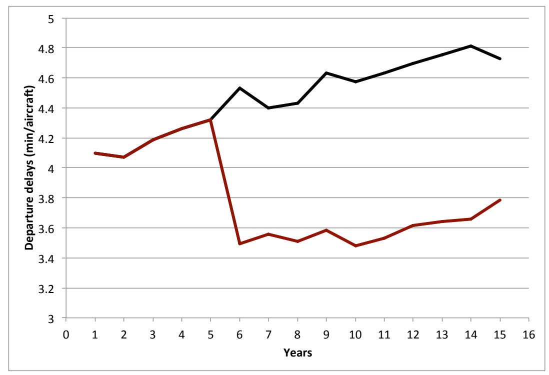


(e) Total utilization ratio.

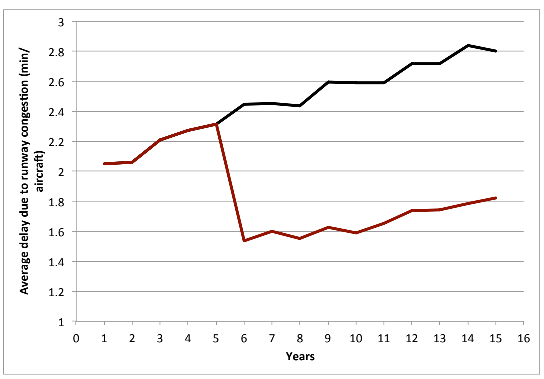
Figure 114: Impact of lighting technology (in red) on baseline utilization ratios (in black).



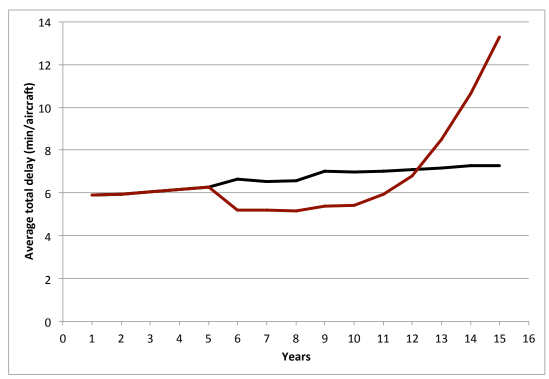
(a) Arrival delays (min/aircraft).



(b) Departure delays (min/aircraft).



(c) Average delay due to runway congestion (min/aircraft).



(d) Average total delay (min/aircraft)

Figure 115: Impact of lighting technology (in red) on baseline delays (in black).

Investigating the impact of portfolio #2 on delays shows that the benefit of that portfolio on arrival delays (Figure 115(a)) and average total delays (Figure 115(d)) fades with time. Most importantly, it sheds light on the significant increase in the average total delays after Year 10. In other words, lighting technology helps reduce the average total delays but only to a certain extent. It cannot, by itself, guarantee an acceptable level of delays for the entire timeframe considered.

Deploying additional technologies does little to address this problem, as illustrated in Figures 116. In particular, Figure 117 shows that, while investing in Portfolio #31 allows the airport to accommodate more operations before experiencing significant delays, technologies, alone, are not sufficient to address this issue.

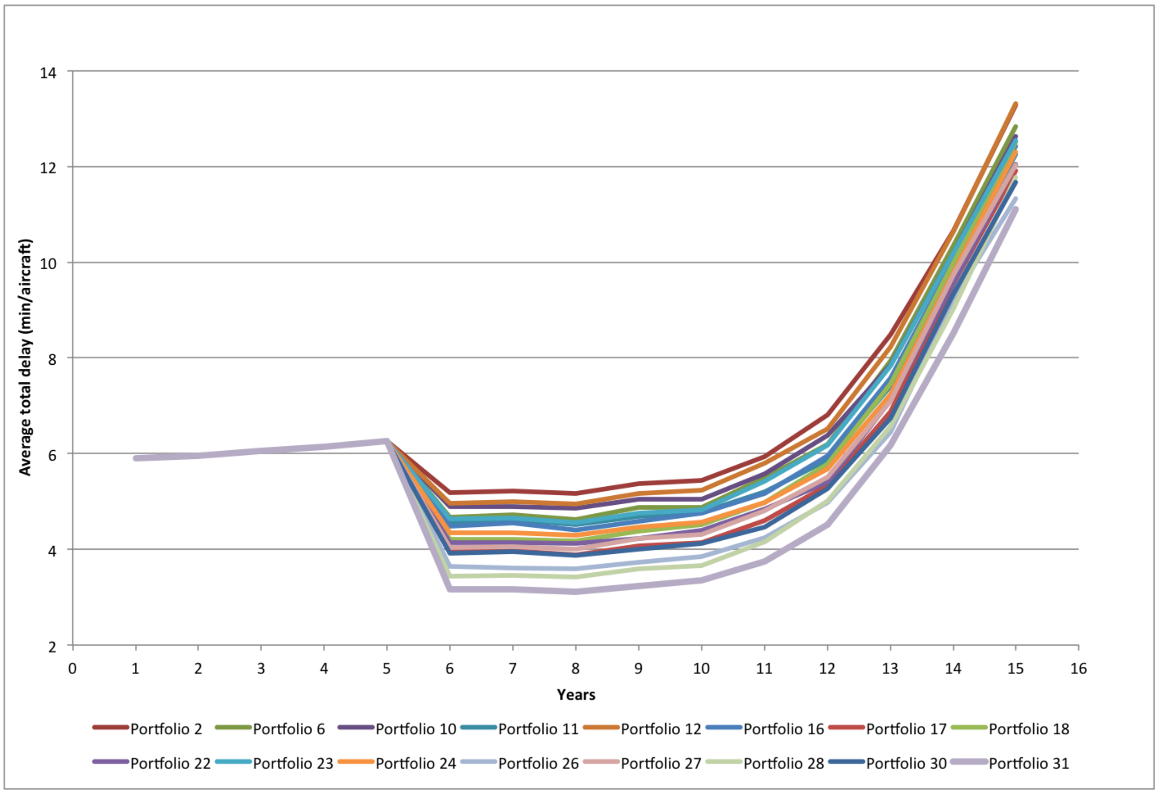


Figure 116: Average total delays (min/aircraft) for all Scenario #2 portfolios with lighting technology at *Airport #2.*

Most importantly, it highlights the fact that this increase in airside delays occurs despite a relatively steady level of delay due to runway congestion. In other words, the delays experienced at the airside level are not caused by runway congestion. Rather, these delays may find their origin at the gate level, meaning that the number or type of gates available is insufficient to accommodate the increased level of traffic. Hence, this work helps identify:

- When/whether additional technologies are required: the example provided has shown that lighting technology by itself is sufficient for up to ~165 daily operations

- When the airport infrastructure becomes the constraining factor (i.e. when deploying additional technologies does not lead to any improvement in airport performance)

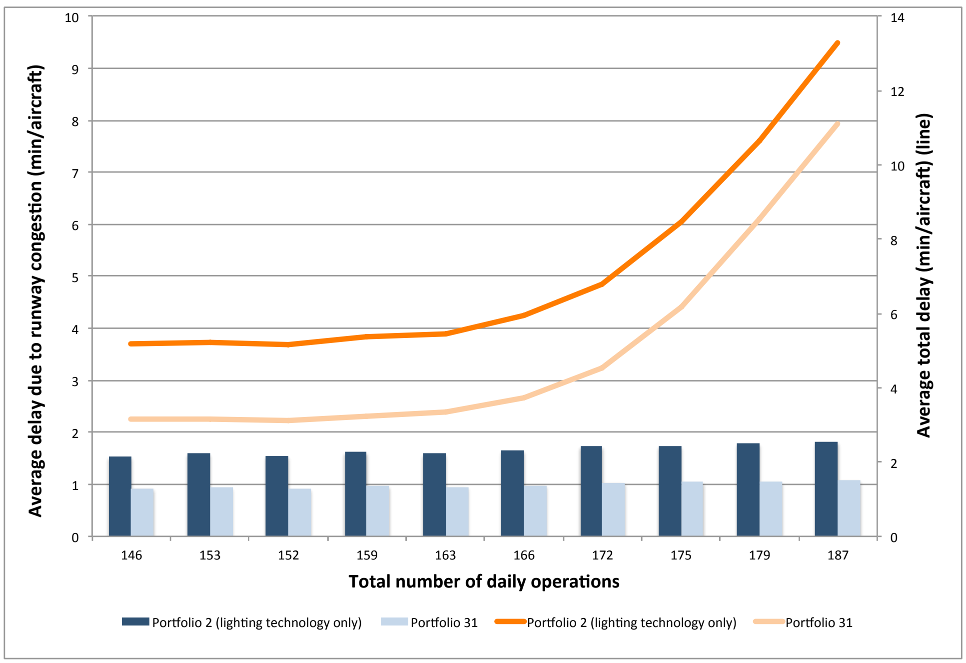


Figure 117: Variations in average total delays and delays due to runway congestion for Portfolios #2 and #31 as a function of the number of daily operations.

Finally, Figures 118 and 119 shows how the portfolios perform with respect to one another across all the responses of interest.

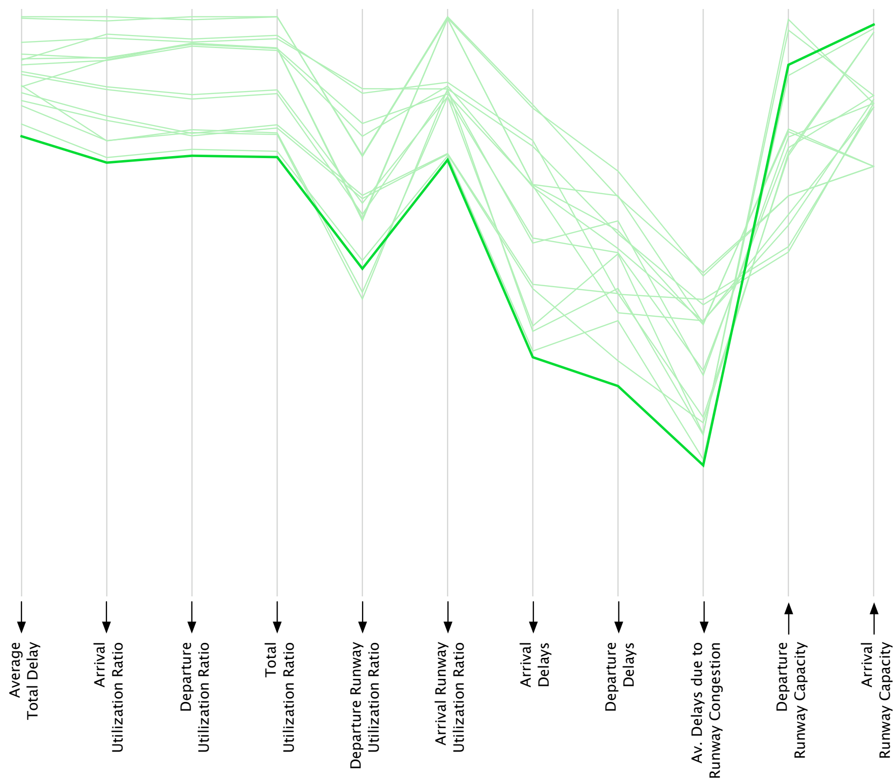


Figure 118: Performance of the best portfolio with lighting technology under Scenario #2 at Year 15.

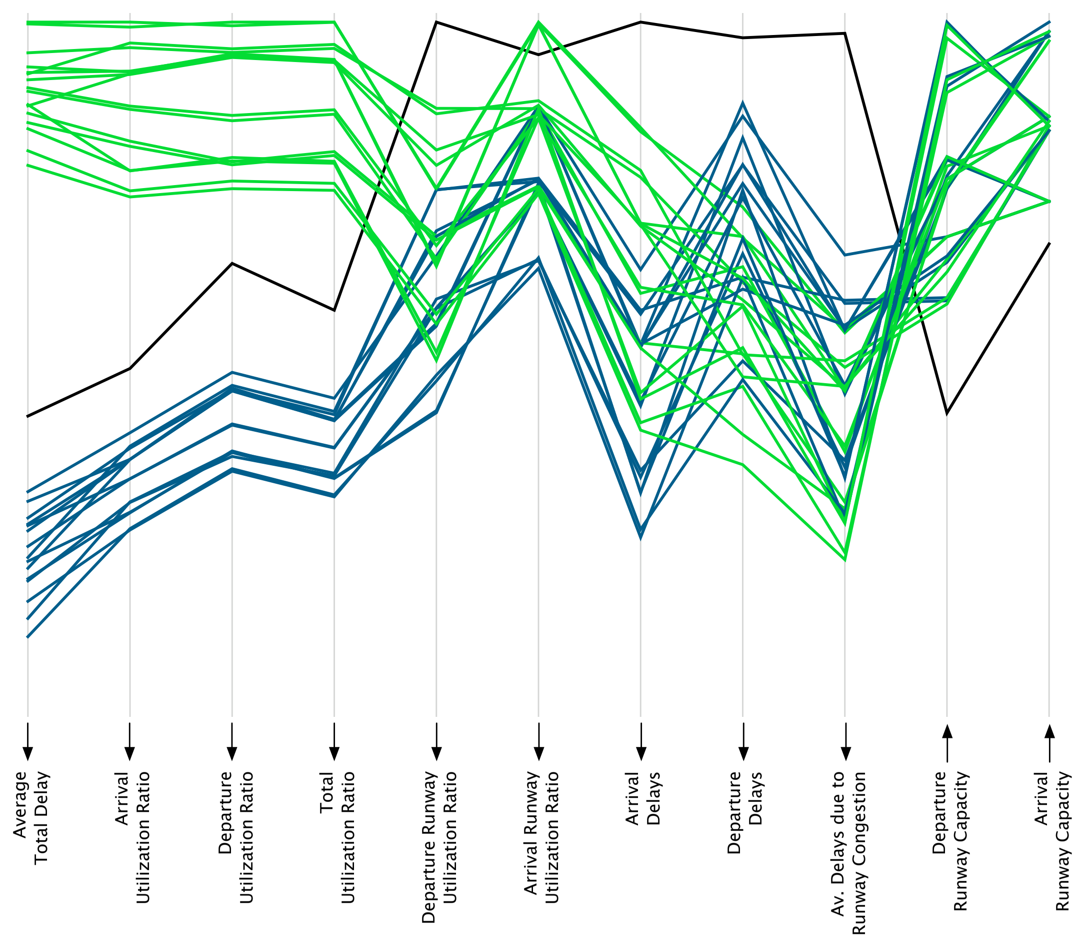


Figure 119: All portfolios (baseline: black, with lighting technologies: green, without lighting technologies: blue) under Scenario #2 for *Airport #2*.

8.1.5 Discussion on Airport #2 Scenario #3

As for *Airport #1*, investment under Scenario #3 only occurs at Year 10. The portfolios and their respective technologies for this scenario are listed in Table 53.

Table 53: Airport #2 Scenario #3 portfolios and their technologies

Portfolios	Technologies	Observations	Portfolios	Technologies	Observations
$P_{2S3}1$	T_{30}	No flights after dark	$P_{2S3}32$	T_{28}, T_{21}, T_5	
$P_{2S3}2$	T_{28}	No flights after dark	$P_{2S3}33$	T_{28}, T_{21}, T_3	
$P_{2S3}3$	T_{21}		$P_{2S3}34$	T_{28}, T_{21}, T_{29}	
$P_{2S3}4$	T_5	No flights after dark	$P_{2S3}35$	T_{28}, T_5, T_3	No flights after dark
$P_{2S3}5$	T_3	No flights after dark	$P_{2S3}36$	T_{28}, T_5, T_{29}	No flights after dark
$P_{2S3}6$	T_{29}	No flights after dark	$P_{2S3}37$	T_{28}, T_3, T_{29}	No flights after dark
$P_{2S3}7$	T_{30}, T_{28}	No flights after dark	$P_{2S3}38$	T_{21}, T_5, T_3	
$P_{2S3}8$	T_{30}, T_{21}		$P_{2S3}39$	T_{21}, T_5, T_{29}	
$P_{2S3}9$	T_{30}, T_5	No flights after dark	$P_{2S3}40$	T_{21}, T_3, T_{29}	
$P_{2S3}10$	T_{30}, T_3	No flights after dark	$P_{2S3}41$	T_5, T_3, T_{29}	No flights after dark
$P_{2S3}11$	T_{30}, T_{29}	No flights after dark	$P_{2S3}42$	$T_{30}, T_{28}, T_{21}, T_5$	
$P_{2S3}12$	T_{28}, T_{21}		$P_{2S3}43$	$T_{30}, T_{28}, T_{21}, T_3$	
$P_{2S3}13$	T_{28}, T_5	No flights after dark	$P_{2S3}44$	$T_{30}, T_{28}, T_{21}, T_{29}$	
$P_{2S3}14$	T_{28}, T_3	No flights after dark	$P_{2S3}45$	T_{30}, T_{28}, T_5, T_3	No flights after dark
$P_{2S3}15$	T_{28}, T_{29}	No flights after dark	$P_{2S3}46$	$T_{30}, T_{28}, T_5, T_{29}$	No flights after dark
$P_{2S3}16$	T_{21}, T_5		$P_{2S3}47$	$T_{30}, T_{28}, T_3, T_{29}$	No flights after dark
$P_{2S3}17$	T_{21}, T_3		$P_{2S3}48$	T_{30}, T_{21}, T_5, T_3	
$P_{2S3}18$	T_{21}, T_{29}		$P_{2S3}49$	$T_{30}, T_{21}, T_5, T_{29}$	
$P_{2S3}19$	T_5, T_3	No flights after dark	$P_{2S3}50$	$T_{30}, T_{21}, T_3, T_{29}$	
$P_{2S3}20$	T_5, T_{29}	No flights after dark	$P_{2S3}51$	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S3}21$	T_3, T_{29}	No flights after dark	$P_{2S3}52$	T_{28}, T_{21}, T_5, T_3	
$P_{2S3}22$	T_{30}, T_{28}, T_{21}		$P_{2S3}53$	$T_{28}, T_{21}, T_5, T_{29}$	
$P_{2S3}23$	T_{30}, T_{28}, T_5	No flights after dark	$P_{2S3}54$	$T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S3}24$	T_{30}, T_{28}, T_3	No flights after dark	$P_{2S3}55$	T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S3}25$	T_{30}, T_{28}, T_{29}	No flights after dark	$P_{2S3}56$	T_{21}, T_5, T_3, T_{29}	
$P_{2S3}26$	T_{30}, T_{21}, T_5		$P_{2S3}57$	$T_{30}, T_{28}, T_{21}, T_5, T_3$	
$P_{2S3}27$	T_{30}, T_{21}, T_3		$P_{2S3}58$	$T_{30}, T_{28}, T_{21}, T_5, T_{29}$	
$P_{2S3}28$	T_{30}, T_{21}, T_{29}		$P_{2S3}59$	$T_{30}, T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S3}29$	T_{30}, T_5, T_3	No flights after dark	$P_{2S3}60$	$T_{30}, T_{28}, T_5, T_3, T_{29}$	No flights after dark
$P_{2S3}30$	T_{30}, T_5, T_{29}	No flights after dark	$P_{2S3}61$	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S3}31$	T_{30}, T_3, T_{29}	No flights after dark	$P_{2S3}62$	$T_{28}, T_{21}, T_5, T_3, T_{29}$	
			$P_{2S3}63$	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	

Similarly to *Airport #2* Scenario #2, the presence, or not, of a lighting technology has a significant impact on the airport utilization ratio and the ability of technologies as a whole to address airside delays. As illustrated in Figure 120, *Airport #2* under Scenario #3 also experiences a significant increase in average total delays despite the deployment of multiple technologies and a steady level of delay due to runway congestion.

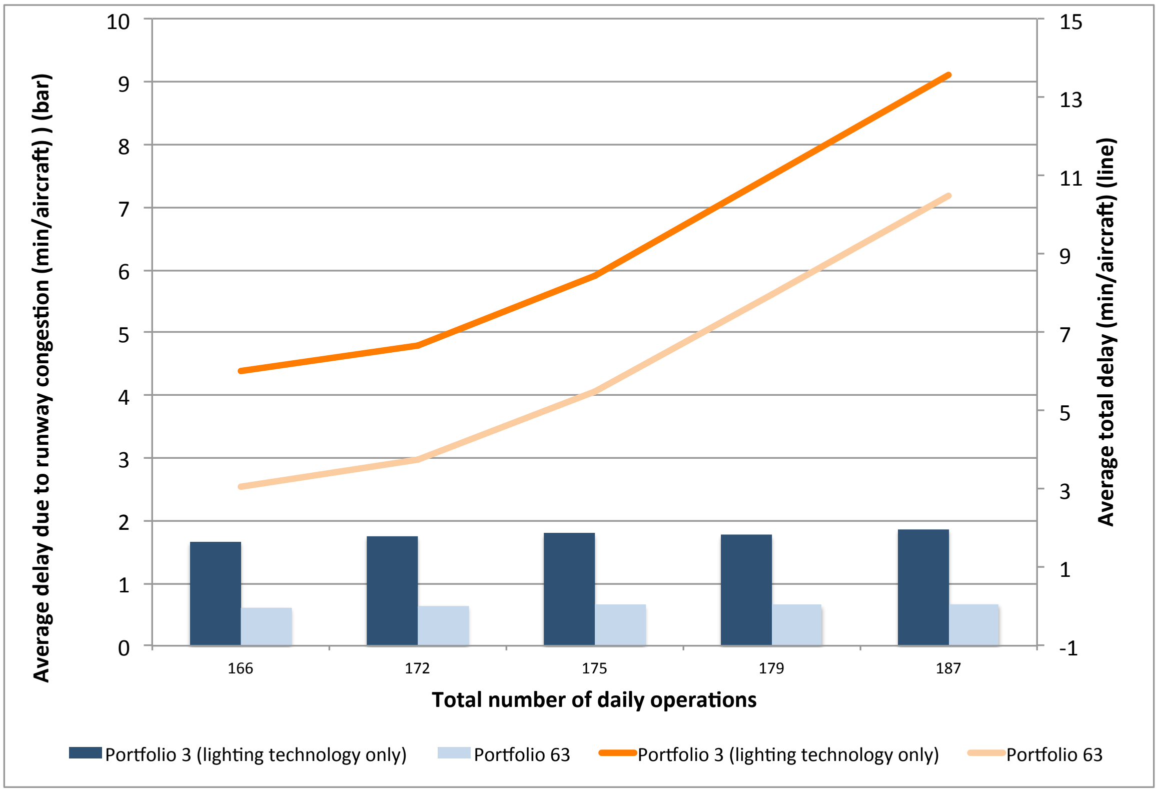


Figure 120: Variations in average total delays and delays due to runway congestion for Portfolio #3 and #63 as a function of the number of daily operations.

Figure 121 enables a quick comparison of all portfolios (with and without lighting technologies) across all the responses of interest. In particular, Figure 122 illustrates the observation made for Scenario #2 that no portfolio emerges that would perform best in all dimensions.

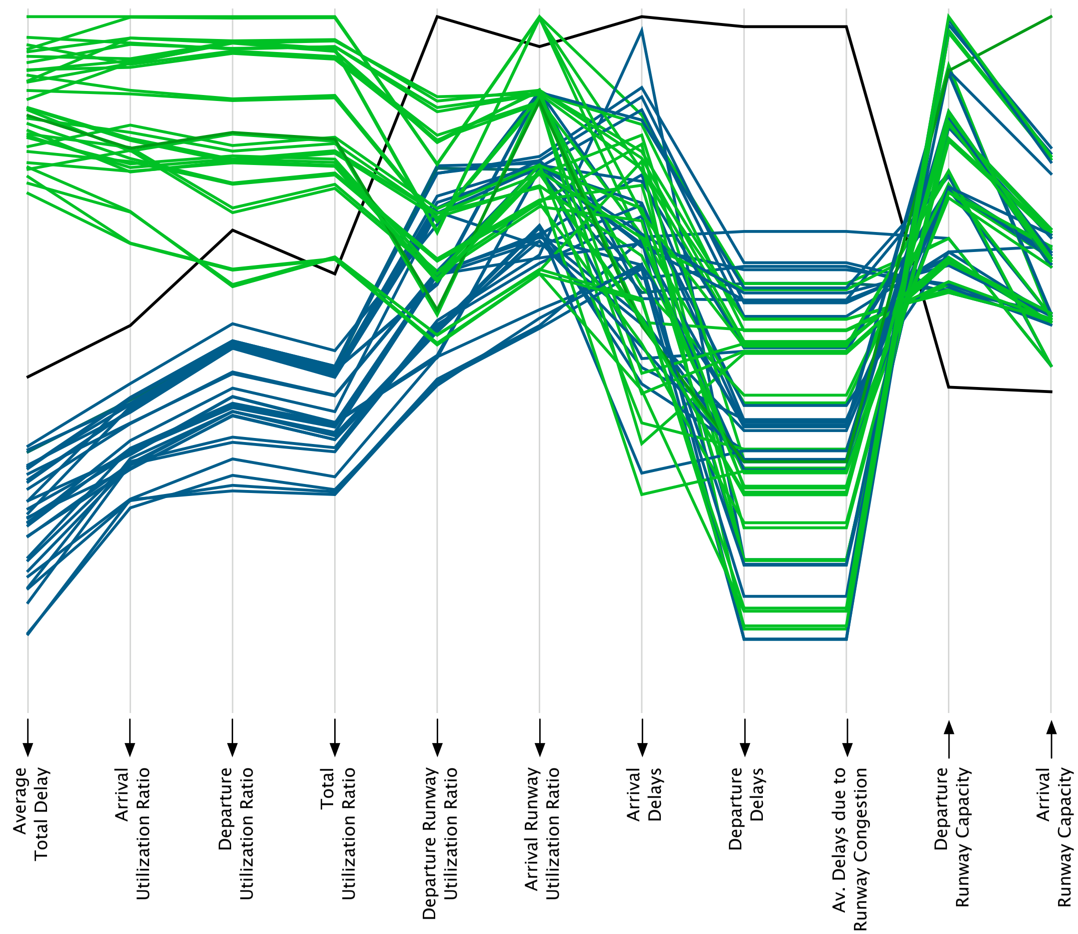
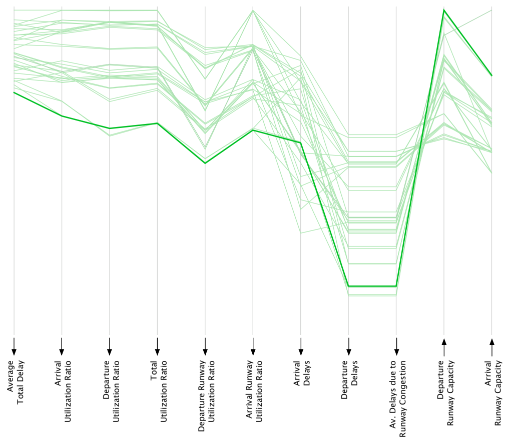
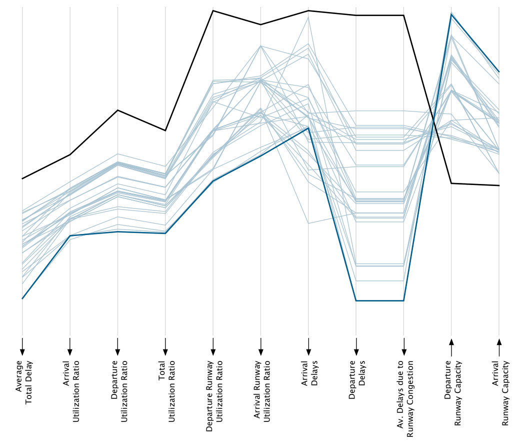


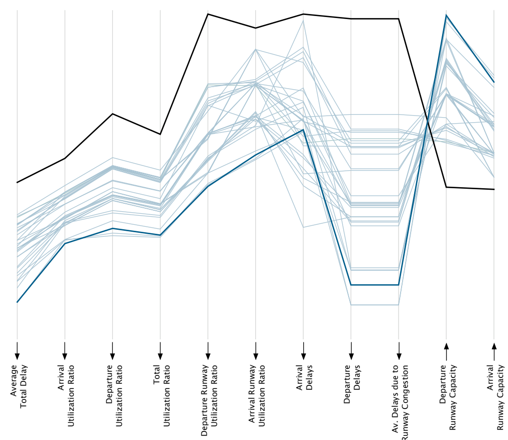
Figure 121: All portfolios (baseline: black, with lighting technologies: green, without lighting technologies: blue) under Scenario #3 for *Airport #2*.



(a) Scenario #3 portfolio #63 performance.



(b) Scenario #3 portfolio #47 performance (no lighting technology, baseline in black).



(c) Scenario #3 portfolio #60 performance (no lighting technology, baseline in black).

Figure 122: Performance of the best portfolios with (in green) and without (in blue) lighting technology under Scenario #3 at Year 15.

8.1.6 Discussion on Airport #2 Scenario #4 and Observations on Airport #2 Investment Scenarios

Under Scenario #4, portfolios from Scenario #2 are deployed from Year 6 to Year 10 and further complemented with portfolios from Scenario #3 between Year 11 and Year 15. As such, the airport is provided with two opportunities to invest in lighting technology: at Year 6 or at Year 11. The resulting 391 portfolios and their technologies are summarized in Appendix G (Tables G.1 through G.10).

Figure 123 illustrates the evolution of the average total delays under all portfolios and all scenarios, with and without the presence of a lighting system. In particular, it shows that, when no lighting technology is in place (left plot), the difference in performance between Year 11 and Year 15 of Scenarios #2, #3 and #4 portfolios is relatively small. In other words, no "time cluster" can be clearly identified as when a lighting system is present (right plot). The right plot in Figure 123 illustrates the observation made previously that the average total delay remains relatively the same from Year 6 to Year 12 for all Scenario #4 portfolios but that it significantly increases from Year 13 to Year 15. In both instances (with and without lighting technology), however, Scenario #4, provides, on average, a better performance in term of total delays than Scenarios #2 and #3.

Table 54 lists the best portfolios and summarizes their performance at Year 15 across all responses of interest and scenarios. In particular, this table shows that portfolios that include lighting technology do not necessarily perform better than portfolios with no such technology. However, while implementing technologies at an airport with no lighting system may not generate much revenues because of the low number of operations to be handled. This, in turn, could prevent the investment in these technologies in the first place, as further discussed in Section 8.2.

Table 54: Best portfolios and their corresponding technologies at Year 15 for all responses and scenarios (*Airport #2*)

Responses	Scenarios	Technologies		Best	
		No Lighting	Lighting	No Lighting	Lighting
Average total delay (min/aircraft)	S1	-	-	-	-
	S2	$P_{2S2}29$: T_{21}, T_5, T_3, T_{29}	$P_{2S2}31$: T_{30}, T_{21}, T_5, T_3, T_{29}	3.89	11.11
	S3	$P_{2S3}47$: T_{30}, T_{28}, T_3, T_{29}	$P_{2S3}63$: T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	2.74	10.50
	S4*	T_{30}, T_{28}, T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	2.74	10.50
Arrival utilization ratio	S1	-	-	-	-
	S2	$P_{2S2}19$: T_{30}, T_5, T_3	$P_{2S2}31$: T_{30}, T_{21}, T_5, T_3, T_{29}	0.11	0.22
	S3	$P_{2S3}60$: T_{30}, T_{28}, T_5, T_3, T_{29}	$P_{2S3}63$: T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.10	0.19
	S4*	T_{30}, T_{28}, T_5, T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.10	0.19
Departure utilization ratio	S1	-	-	-	-
	S2	$P_{2S2}19$: T_{30}, T_5, T_3	$P_{2S2}31$: T_{30}, T_{21}, T_5, T_3, T_{29}	0.09	0.15
	S3	$P_{2S3}47$: T_{30}, T_{28}, T_3, T_{29}	$P_{2S3}43$: T_{30}, T_{28}, T_{21}, T_3	0.07	0.12
	S4*	T_{30}, T_{28}, T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_3	0.07	0.12
Total utilization ratio	S1	-	-	-	-
	S2	$P_{2S2}19$: T_{30}, T_5, T_3	$P_{2S2}31$: T_{30}, T_{21}, T_5, T_3, T_{29}	0.10	0.18
	S3	$P_{2S3}47$: T_{30}, T_{28}, T_3, T_{29}	$P_{2S3}63$: T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.08	0.15
	S4*	T_{30}, T_{28}, T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.08	0.15
Departure runway utilization ratio	S1	-	-	-	-
	S2	$P_{2S2}13$: T_5, T_3	$P_{2S2}30$: T_{21}, T_5, T_3, T_{29}	0.17	0.19
	S3	$P_{2S3}60$: T_{30}, T_{28}, T_5, T_3, T_{29}	$P_{2S3}63$: T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.16	0.18
	S4*	T_{30}, T_{28}, T_5, T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.16	0.18
Arrival runway utilization ratio	S1	-	-	-	-
	S2	$P_{2S2}19$: T_{30}, T_5, T_3	$P_{2S2}31$: T_{30}, T_{21}, T_5, T_3, T_{29}	0.26	0.29
	S3	$P_{2S3}47$: T_{30}, T_{28}, T_3, T_{29}	$P_{2S3}63$: T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.21	0.24
	S4*	T_{30}, T_{28}, T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.21	0.24
Arrival delays (min/aircraft)	S1	-	-	-	-
	S2	$P_{2S2}19$: T_{30}, T_5, T_3	$P_{2S2}31$: T_{30}, T_{21}, T_5, T_3, T_{29}	1.03	1.35
	S3	$P_{2S3}60$: T_{30}, T_{28}, T_5, T_3, T_{29}	$P_{2S3}63$: T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.77	1.07
	S4*	T_{30}, T_{28}, T_5, T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	0.77	1.07
Departure delays (min/aircraft)	S1	-	-	-	-
	S2	$P_{2S2}29$: T_{30}, T_5, T_3, T_{29}	$P_{2S2}31$: T_{30}, T_{21}, T_5, T_3, T_{29}	2.83	2.36
	S3	$P_{2S3}47$: T_{30}, T_{28}, T_3, T_{29}	$P_{2S3}59$: T_{30}, T_{28}, T_{21}, T_3	1.84	1.72
	S4*	T_{30}, T_{28}, T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_3	1.84	1.72
Av. delays due runway congestion (min/aircraft)	S1	-	-	-	-
	S2	$P_{2S2}19$: T_{30}, T_5, T_3	$P_{2S2}31$: T_{30}, T_{21}, T_5, T_3, T_{29}	1.21	1.08
	S3	$P_{2S3}24$: T_{30}, T_{28}, T_3	$P_{2S3}43$: T_{30}, T_{28}, T_{21}, T_3	0.55	0.59
	S4*	T_{30}, T_{28}, T_3	T_{30}, T_{28}, T_{21}, T_3	0.55	0.59
Departure runway capacity (aircraft/hr)	S1	-	-	-	-
	S2	$P_{2S2}13$: T_5, T_3	$P_{2S2}30$: T_{21}, T_5, T_3, T_{29}	27.1	27
	S3	$P_{2S3}60$: T_{30}, T_{28}, T_5, T_3, T_{29}	$P_{2S3}63$: T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	28.5	28.6
	S4*	T_{30}, T_{28}, T_5, T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	28.5	28.6
Arrival runway capacity (aircraft/hr)	S1	-	-	-	-
	S2	$P_{2S2}19$: T_{30}, T_5, T_3	$P_{2S2}31$: T_{30}, T_{21}, T_5, T_3, T_{29}	18.4	18.2
	S3	$P_{2S3}47$: T_{30}, T_{28}, T_3, T_{29}	$P_{2S3}56$: T_{21}, T_5, T_3, T_{29}	22.1	26.6
	S4*	T_{30}, T_{28}, T_3, T_{29}	T_{21}, T_5, T_3, T_{29}	22.1	26.6

* Multiple portfolios

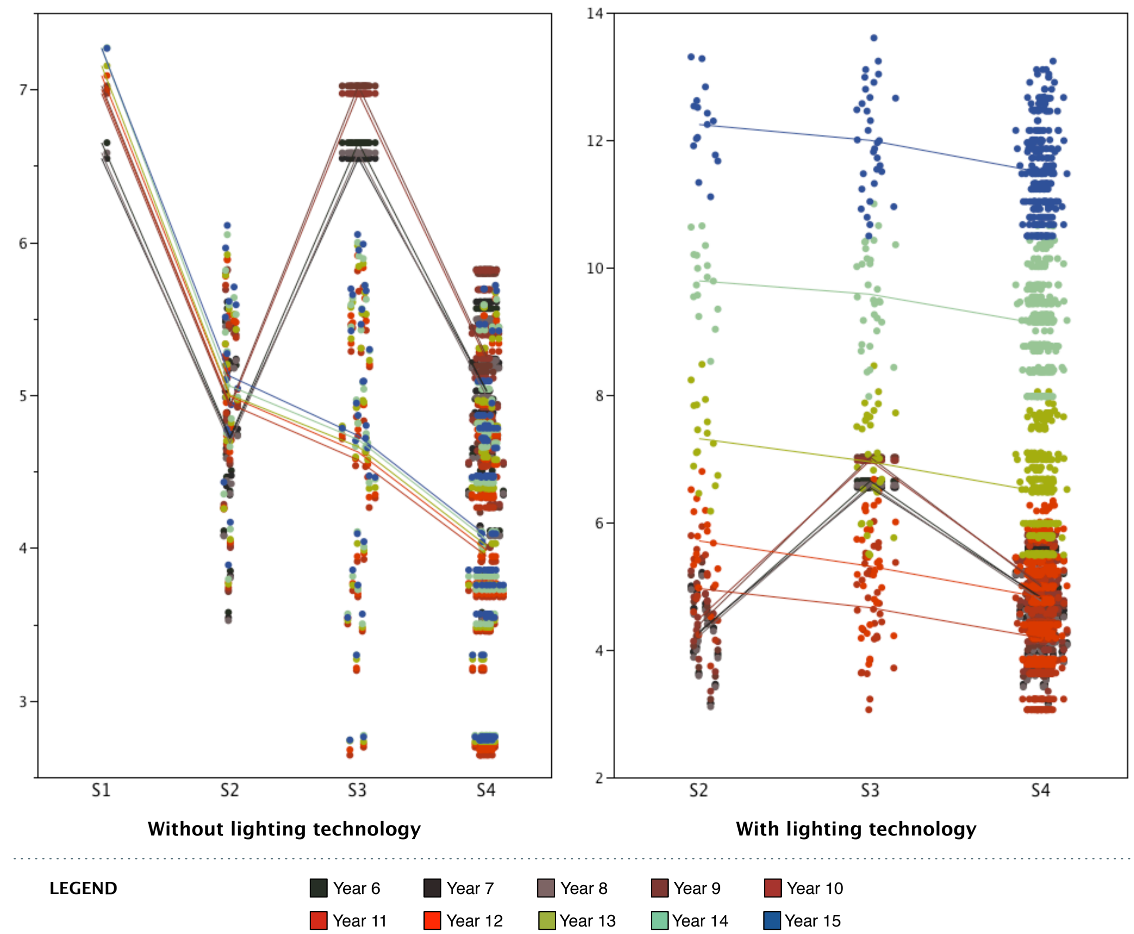


Figure 123: Average total delays (min/aircraft) for all scenarios portfolios with and without lighting technology at *Airport #2*.

8.1.6.1 Technology Ranking

The approach followed to rank technologies under *Airport 1* Scenario #4 is repeated for the*Airport #2* technology list (Table 55). The technologies are ranked for all responses of interest and all *Airport #2* scenarios (Figure 124). The ranking also accounts for the presence, or not, of lighting technology. Because the lighting technology T_{21} does not have a direct impact on the responses of interest (Table 43), it does not explicitly appear in the list of technologies ranked but is assumed present for rankings under the "With lighting tech." category (Figure 124). Ranking technologies depending on the presence of a lighting system helps identify the impact that different levels of traffic have on their performance. As such, it also provides a better understanding of the impact that traffic has on the desirability of certain technologies.

Table 55: Technologies considered for future investment options at airport #2

ID	Technology Name
T_3	Multilateration (MLAT)
T_5	Legacy Secondary Surveillance Radar (SSR)
T_{21}	Switchable Center Line Lights and Stop Bars
T_{28}	Departure MANager (DMAN)
T_{29}	Surface MANager (SMAN)
T_{30}	Arrival MANager (AMAN)

Remarks on Scenario #2

First it can be observed that T_3 (Multilateration (MLAT)) systematically ranks among the top technologies, independent of the presence of a lighting system. In particular, it ranks better than T_5 (Legacy Secondary Surveillance Radar (SSR)) in 7 out of the 11 responses considered, making it more desirable than a SSR. The difference between theses two complementary, yet competitive technologies, is particularly noticeable when looking at the average total delays and the arrival side of airport operations (arrival runway utilization ratio and arrival runway capacity) (Figure 125).

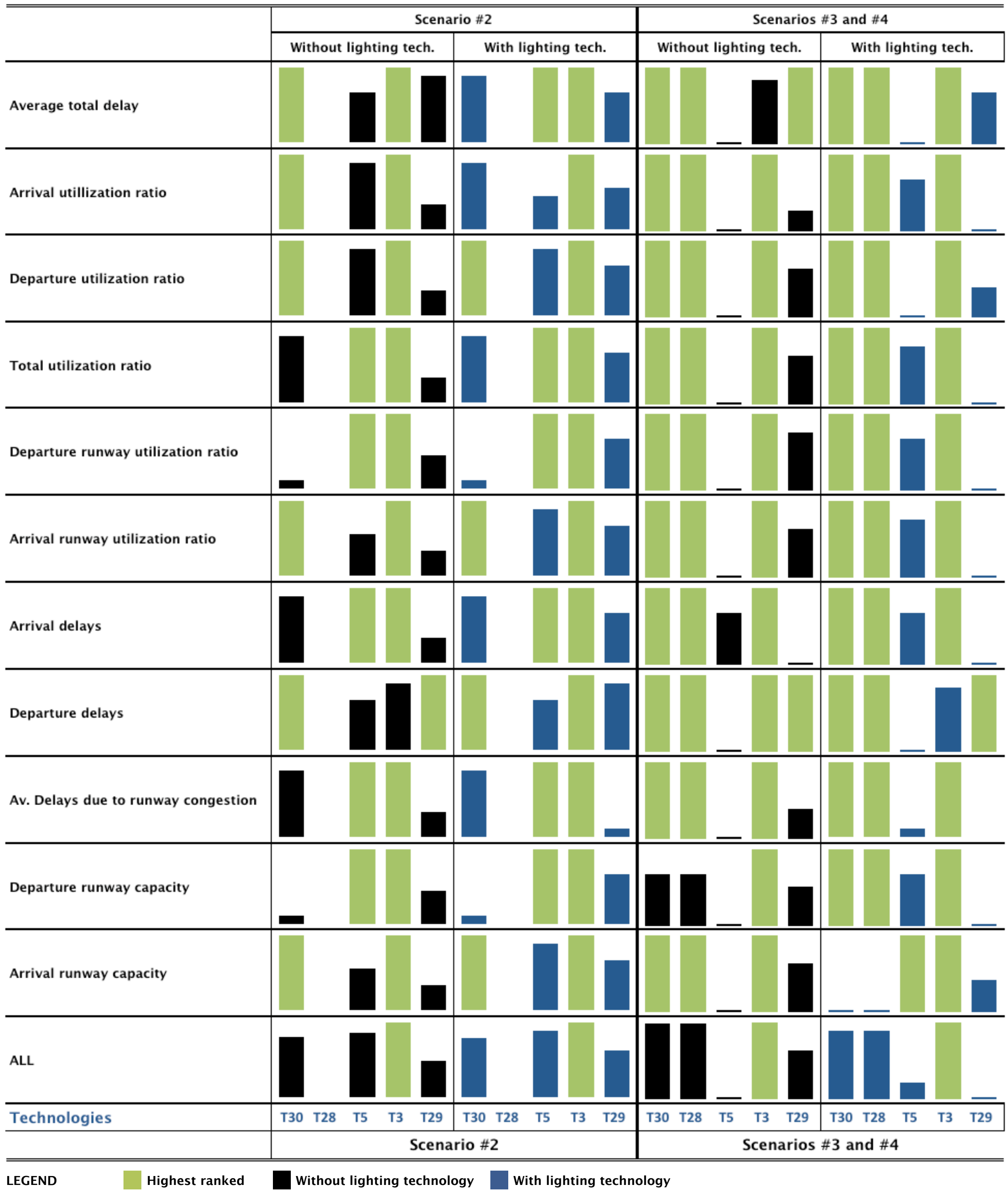


Figure 124: Technology ranking across *Airport #2* scenarios at Y15.

Finally, while the level of traffic does not seem to have an impact on the ranking of T_{30} (Arrival MANager (AMAN)), it does have a positive impact on the desirability of T_{29} (Surface MANager (SMAN)) for higher levels of traffic.

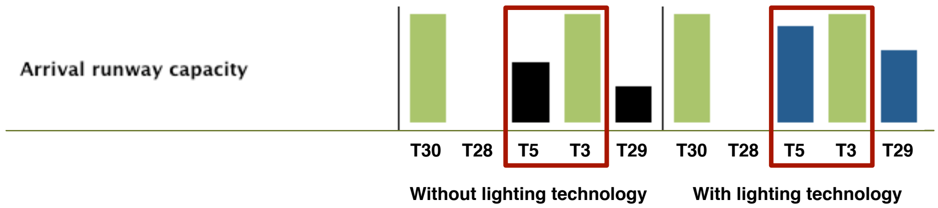


Figure 125: Technology ranking for arrival runway capacity under *Airport #2* Scenario #2 at Y15 with and without lighting technology.

Remarks on Scenarios #3 and #4

Under these scenarios, the level of traffic seems to have a significant impact on the desirability of T_5 (Legacy Secondary Surveillance (SSR) Radar). In particular, higher levels of traffic seems to positively influence the ranking of T_5 when looking at utilization ratios (arrival utilization ratio, total utilization ratio, departure and arrival runway utilization ratio), as well as departure runway capacity, and delays due to runway congestion to some extent. Interestingly, this increase in desirability seems to occur to the detriment of T_{29} (Surface MANager (SMAN)) (Figure 126).

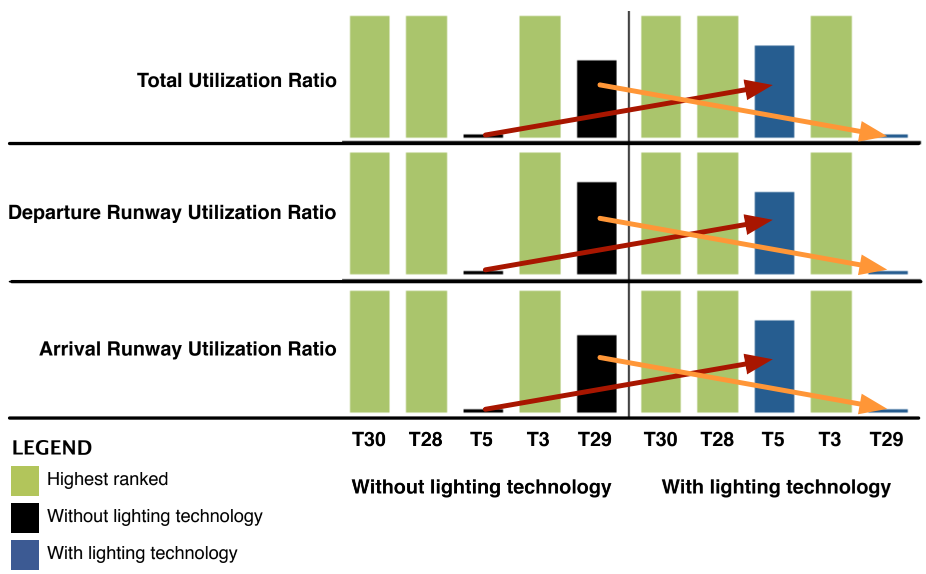


Figure 126: Technology ranking for different utilization ratios under *Airport #2* Scenario #3 at Y15 with and without lighting technology.

Finally, as with Scenario #2, T_3 (Multilateration (MLAT)) ranks significantly higher than T_5 (Legacy Secondary Surveillance Radar (SSR), making T_3 the most "robust' technology with respect to investment timing and level of traffic.

8.1.7 Preliminary Remarks on the Performance Assessment

This section summarizes the main observations made regarding the performance assessment of the technologies considered. First, as discussed in Section 7.4, the formulation of technology portfolios represents a huge combinatorial problem. This problem is further exacerbated by the different investment scenarios under study. In particular, Figure 127 illustrates the impact on the number of portfolios of considering two additional technologies for investment (*Airport #1* considers 4 technologies and *Airport #2*, 6 technologies). More importantly, it highlights the difficulty to study the impact of a high number of technologies in a short amount of time (running each portfolio (repeated 500 times) through MACAD takes an average of 7 hours on an 8-processor computer).

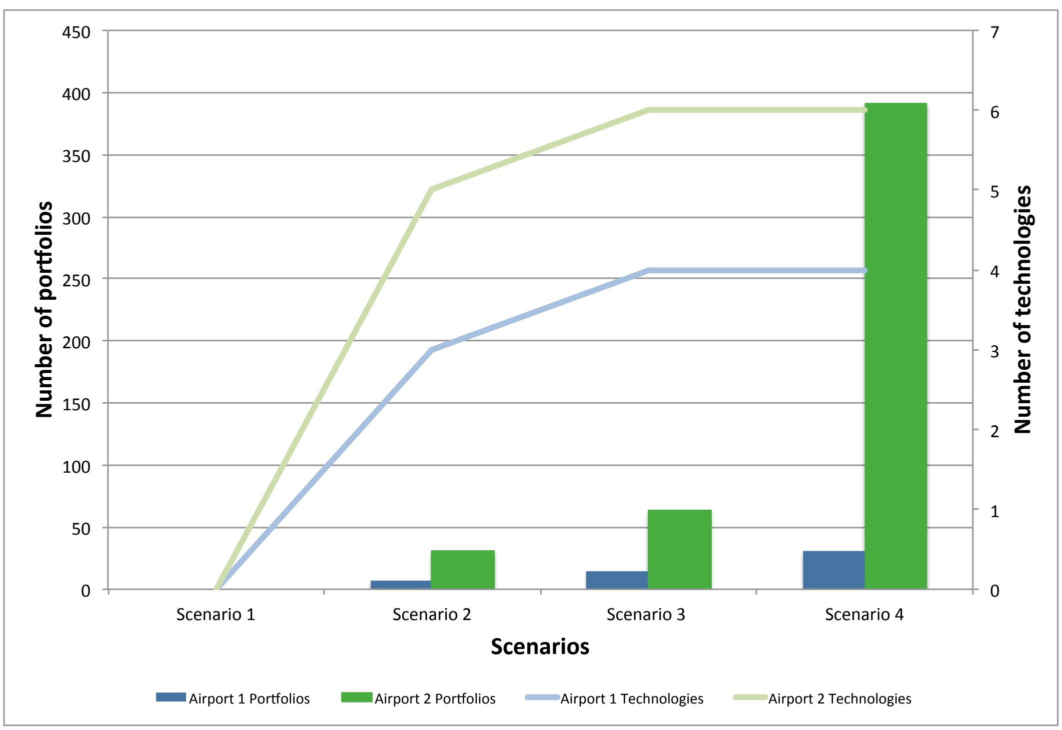


Figure 127: Illustration of the combinatorial problem.

The discussion on the performance of the different portfolios across all scenarios for the two airports considered has also highlighted the following points:

- The method developed helps identify
  - Grouping of portfolios, i.e. portfolios that perform similarly on a given response: this information can eventually be valuable in helping the decision maker choose the most cost-effective portfolio among ones having similar impacts.
  - When/whether additional technologies are required: the example provided has shown that lighting technology by itself is sufficient for up to $\sim$ 165 daily operations
  - When the airport infrastructure becomes the constraining factor (i.e. when deploying additional airside technologies does not lead to any improvement in airport delay performance)
- Scenario #4 for both airports performed on average better than Scenarios #1, #2, and #3. However, the variability in the performance of Scenario #4 portfolios is significant. Hence, attention should be paid regarding which portfolio to choose, as there exist many portfolios under Scenario #4 that perform worse than some portfolios under Scenario #2 or #3. As previously stated, deciding to follow Scenario #4 does not automatically result in increased performance.
- For *Airport #1*, pursuing Scenario #2 over Scenario #3 seems preferable
- For *Airport #1*, the combination T_{30}/T_{28} (AMAN/DMAN) seems to perform better, under the defined set of assumptions and conditions, than the combination T_{30}/T_{29} (AMAN/SMAN). Consequently, if one were to consider pursuing investment scenario #4, investing in technologies T_{30} and T_3 for the period Y6-Y10 and then complementing that portfolio with technology T_{28} for the period Y11-Y15 would appear

as a good approach

- T_3 (Multilateration (MLAT)) systematically ranks among the top technologies, and this, independently of the presence of a lighting system (and consequently the level of traffic). In particular, T_3 ranks significantly higher than T_5 (Legacy Secondary Surveillance (SSR) Radar), and appears as the most "robust" technology with respect to investment timing and level of traffic.

- While *Airport #2* with no lighting system tends to perform better, from a delay perspective, than when a lighting system is present, the limited amount of revenues it generates might not be sufficient to offset the cost of the technologies in place or acquired. Hence, while understanding the impact that technologies have on airport performance is crucial, investing in technology portfolios cannot solely be based upon performance evaluation, as further discussed in the following section.

8.2 *Flexibility Assessment*

The following section (Section 8.2.1) discusses the impact of each investment scenario on the annual revenues of both airports. Section 8.2.2 then presents the results of the implementation of Real Options Analysis to the problem at hand. In particular, it discusses the strategic value of embedding flexibility in the formulation of technology portfolios and the definition of investment options. Finally, Section 8.2.3 describes the tradeoff between performance and strategic value.

8.2.1 Impact of Investment Scenarios on Airport Revenues

As established in Section 6.4.1, airport revenues are sensitive to the number of arrivals, the mix of aircraft (small vs. medium) and the average total delay per aircraft. The following sections illustrate how the performance of technology portfolios translate into increased revenues.

8.2.1.1 For Airport #1

Figure 128 describes the evolution of *Airport #1* annual revenues under the best portfolios (in terms of revenues generated) for each investment scenario considered. It shows that the impact of congestion on revenues (Section 6.2.3.3) under these portfolios and scenarios can be felt later (around Year 11 depending on the scenario) than for the baseline. Hence, no portfolio or investment scenario, under the assumptions and conditions of this problem, seems to fully alleviate the loss in revenues due to congestion for the timeframe chosen.

Figures 129 and 130 zoom on the time period between years 9 and 12 to help differentiate further the impact of each scenario. These figures show that, by injecting technologies at both Year 5 and Year 10, Scenario #4 leads to the highest level of revenues among all three scenarios. While, as for the baseline, the effect of congestion on revenues can be felt around Year 10, these effects are not as dramatic and still allow the airport to generate more revenues before experiencing a decline. Indeed, the best portfolio under Scenario #4 helps

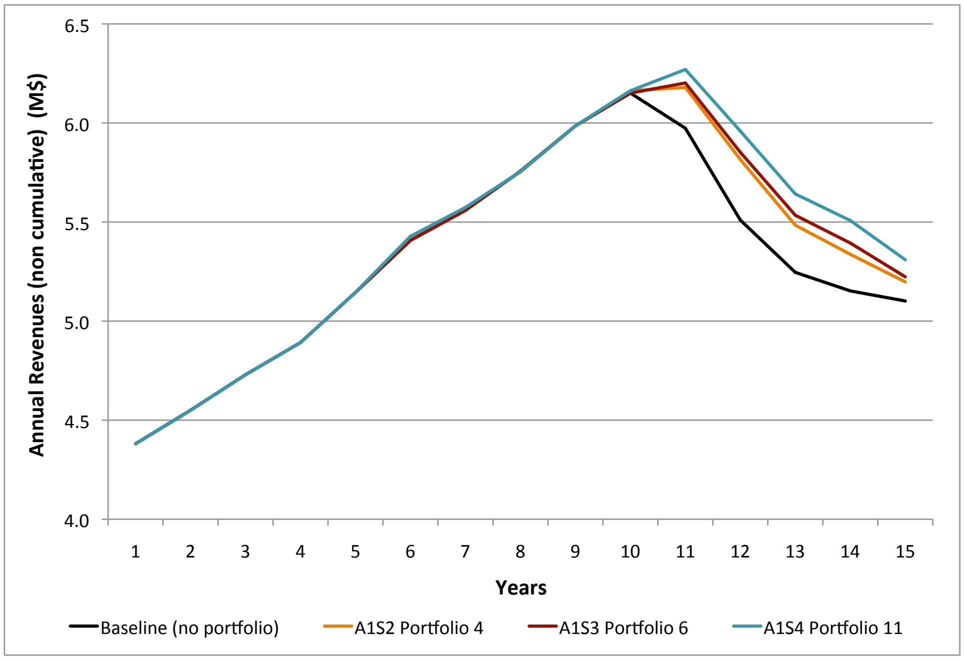


Figure 128: Impact of the different investment scenarios on *Airport #1* annual revenues for the timeframe considered.

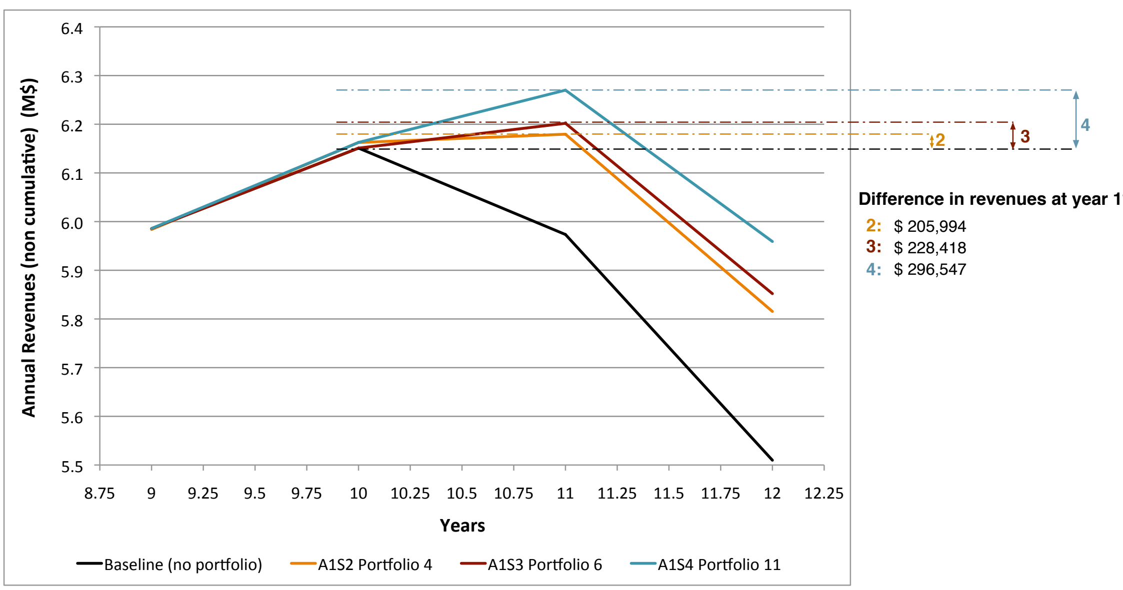


Figure 129: Impact of the different investment scenarios on *Airport #1* annual revenues from year 9 to 12.

delays the effect of congestion on revenues by ~1 year when compared with the baseline.

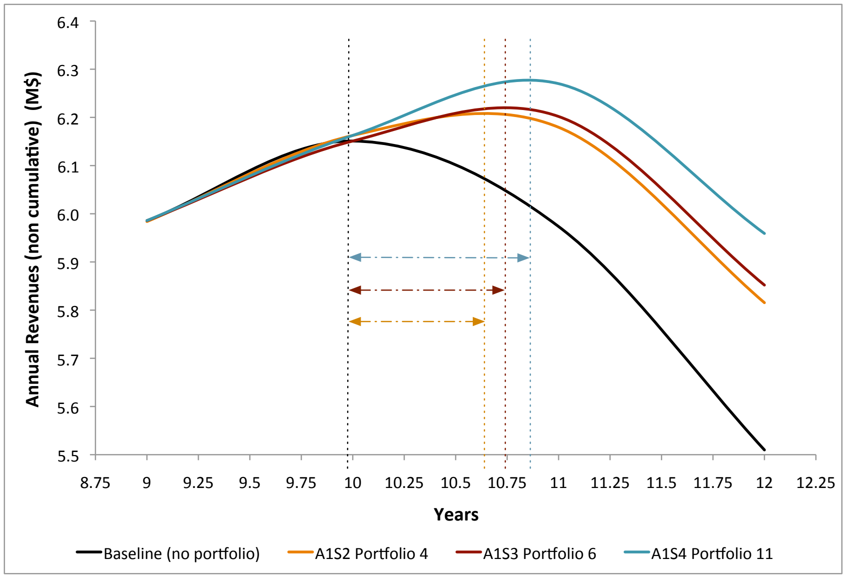


Figure 130: Impact of the different investment scenarios on *Airport #1* annual revenues from year 9 to 12 (smoothed lines).

8.2.1.2 For Airport #2

For *Airport #2*, the level of traffic remains too low (with and without lighting technology) for congestion to reach its threshold and significantly impact revenues. Hence, because revenues, in this case, are solely dependent on the number and mix of aircraft, there are no noticeable differences between investment scenarios when no lighting technology is in place (Figure 131). When a lighting technology is in place (Figure 132), the difference in revenues between scenarios depends on when that lighting technology is deployed, which itself depends on the investment scenario chosen. However, while the level of revenues reached at Year 15 is the same for all three scenarios, the amount of revenues cumulated over the 15 years by Scenarios #2 and #4 (M$44.86 and M$44.89, respectively) is much higher than for Scenario #3 (M$37.47).

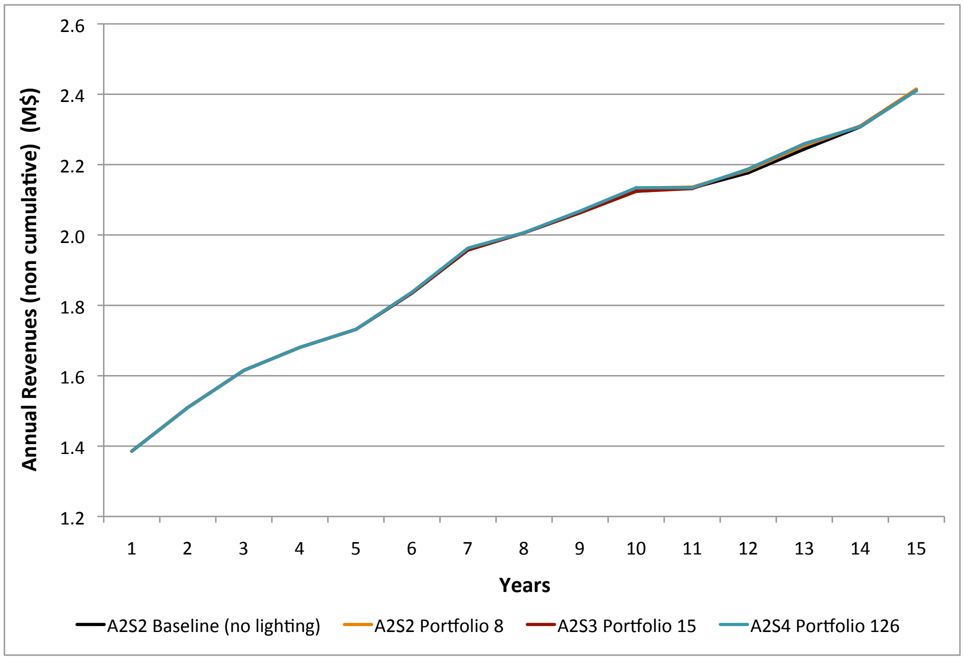


Figure 131: Impact of the different investment scenarios on *Airport #2* annual revenues for the timeframe considered without no lighting technology present.

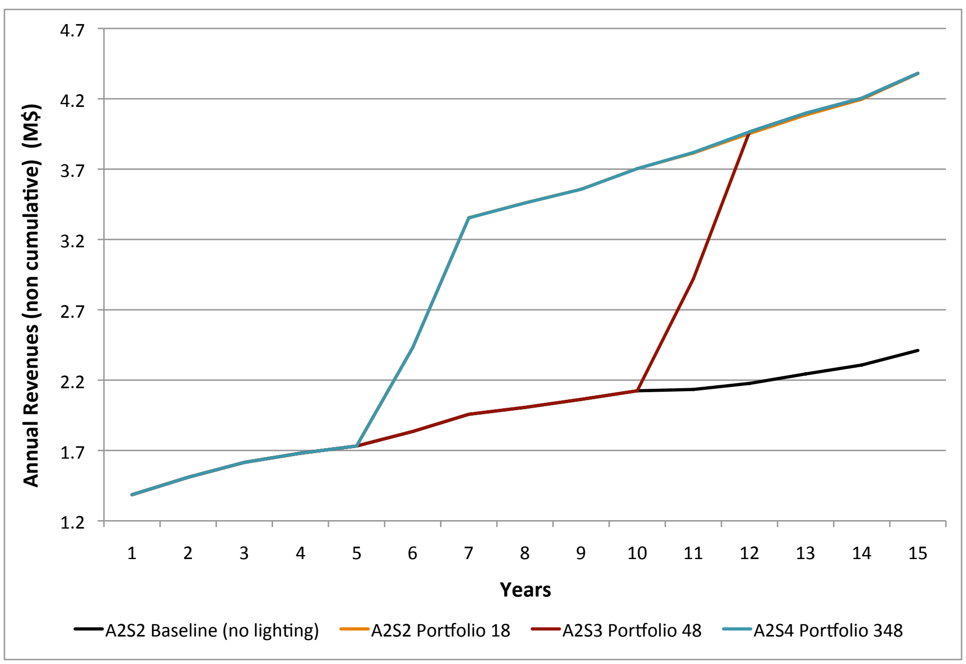


Figure 132: Impact of the different investment scenarios on *Airport #2* annual revenues for the timeframe considered with lighting technology in place.

The following section further extends this discussion to the valuation of technology portfolios and that of flexibility

8.2.2 Flexibility Valuation

As discussed in Chapter 2 Section 2.9.1, flexibility, in the context of this research, is defined at two levels:

- At the system level, flexibility represents *the capability of a portfolio to evolve to respond to changes in requirements occurring after it has been acquired and/or deployed, and this, in a timely and cost-effective manner*.
- At the management level, flexibility represents *the capability to implement mid-course strategy corrections as the future unfolds and some of the uncertainty gets resolved*.

Managerial flexibility and its value are first discussed through the following example: an airport is considering increasing its capacity through the deployment of a set of technologies. Doing so would commit the stakeholders to pay some amount of money for a feasibility study at the beginning of the first year and to acquire a set of technologies at the end of the fifth year. Under traditional valuation methods, the technology portfolio with the highest positive NPV would be chosen (according to the NPV rule, portfolios with negative NPVs are disregarded). The issue with this approach is that commitment is based on the deterministic value of alternatives. However, as illustrated below, deterministic calculations of NPV can underestimate the value of a portfolio because it fails to capture the uncertainty of future cash flows. Let's consider Portfolio #5 under Scenario #2 for *Airport #1*. The detail of its NPV calculation is provide in Table 56. A risk-free rate of 8% is assumed. Training costs for new technologies if any, and maintenance costs, are incurred on the sixth year. The NPV for Portfolio #5 being negative (-M$0.25), traditional valuation methods would disregard it, failing to recognize that there are other courses of action than the "now-or-never-proposition." In reality, the stakeholders are faced with two alternatives. They can decide during the first year to pay some money for a feasibility study, and later (during the fifth year), decide whether or not to invest in new technologies. By doing so, they are buying the right, but not the obligation, to pursue a particular portfolio if the conditions are favorable. If it turns out that the demand has not materialized by the time a decision needs to be taken, they would only lose the money they put in the feasibility study, as opposed to loosing the money required to acquire, install and maintain new technologies that would prove unnecessary. Consequently, the opportunity to invest in a new technology portfolio can be seen as a call option with an expiration time of 5 years, a strike price X of M$1.5 (the sum of the acquisition and installation costs for that portfolio) and an underlying asset S equal to the discounted present value of the portfolio from year 5 to year 14 (M$1.268). The value of that option, as provided by the Black-Scholes model, is M$0.370 (Table 57). Hence, in this instance, the value of the option outweighs the negative NPV.

Table 56: NPV calculation for Portfolio #5 Scenario #2 *Airport #1* (rounded values)

	Years														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Revenues ($M\$$)	4.38	4.55	4.73	4.89	5.15	5.43	5.57	5.75	5.99	6.17	6.01	5.48	5.20	5.15	5.10
Additional operating costs ($M\$$)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Acquisition costs ($M\$$)	-	-	-	-	1.50	-	-	-	-	-	-	-	-	-	-
Installation costs ($M\$$)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annual maintenance costs ($M\$$)	0.91	0.91	0.91	0.91	0.91	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21
Training costs ($M\$$)	-	-	-	-	-	0.20	-	-	-	-	-	-	-	-	-
Total costs ($M\$$)	4.91	4.91	4.91	4.91	6.41	5.41	5.21	5.21	5.21	5.21	5.21	5.21	5.21	5.21	5.21
PV ($M\$$)	-0.53	-0.33	-0.15	-0.01	-0.93	0.01	0.23	0.32	0.42	0.48	0.37	0.12	-0.00	-0.02	-0.04
Investment I_0 ($M\$$)	0.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NPV ($M\$$)	**-0.25**	-	-	-	-	-	-	-	-	-	-	-	-	-	-

The corresponding expanded NPV (eNPV) is obtained by the following equation (Equation 42):

$$\text{Expanded NPV} = \text{Value of Flexibility} + \text{Passive NPV} \tag{42}$$

The eNPV being positive (M$0.118), this portfolio should not be discarded. Hence, the value of managerial flexibility is calculated as the value of the real option and is sometimes referred to as "strategic value". By accounting for both the static NPV and the value of the option, the eNPV criterion (also called strategic NPV) captures the value of active decision making and future investment opportunities.

Tables 57 to 59 summarize the passive NPV, eNPV and value of flexibility for all portfolios and scenarios under *Airport #1*. The corresponding tables for *Airport #2* can be found in Appendix G.2.

One of the limitations of the binomial model is that it does not handle negative underlying values. Consequently, options values cannot be calculated for portfolios with a negative stock price (hence the “n.a” in some of the tables). A stock price can be negative for different reasons. In the case of portfolios P_{12} and P_{14} (Scenario #3 *Airport #1*), for example, the investment occurs after revenues have already started decreasing due to congestion (at Year 10). In addition, the impact of these portfolios is not significant enough to generate the revenues that would help recover from the investment. Portfolio P_{15}, also implemented at Year 10, helps alleviate some of the congestion, but the investment happens too late for it to offset the costs of the technologies involved. Hence, factors such as the timing of the investment and its associated costs should be considered carefully as they have an important impact on the value of flexibility.

Table 57: Passive NPV, eNPV, and flexibility value for *Airport #1* Scenario #2 portfolios (round-up values)

Portfolios	S ($M\$$)	X ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_1	1.711	1.000	0.766	1.045	1.811
P_2	2.149	1.461	1.070	1.183	2.253
P_3	1.964	0.500	1.506	1.629	3.135
P_4	1.511	2.461	-0.602	0.234	-0.368
P_5	1.268	1.500	-0.252	0.370	0.118
P_6	1.752	1.961	0.119	0.557	0.676
P_7	1.070	2.961	-1.617	0.032	-1.586

Table 58: Passive NPV, eNPV, and flexibility value for *Airport #1* Scenario #3 portfolios (round-up values)

Portfolios	S ($M\$$)	X ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_1	0.282	1.000	1.518	0.221	1.739
P_2	0.288	1.000	1.531	0.227	1.758
P_3	0.331	1.461	1.394	0.253	1.647
P_4	0.489	0.500	2.215	0.434	2.649
P_5	0.026	2.000	0.466	0.010	0.476
P_6	0.371	2.461	0.979	0.266	1.245
P_7	0.173	1.500	1.034	0.119	1.153
P_8	0.313	2.461	0.855	0.219	1.074
P_9	0.132	1.500	0.944	0.086	1.030
P_{10}	0.314	1.961	1.107	0.228	1.334
P_{11}	0.120	3.461	-0.063	0.063	0.000
P_{12}	-0.038	2.500	0.076	n.a	n.a
P_{13}	0.200	2.961	0.359	0.123	0.483
P_{14}	-0.027	2.961	-0.130	n.a	n.a
P_{15}	-0.092	3.961	-0.771	n.a	n.a

Table 59: Passive NPV, eNPV, and flexibility value for *Airport #1* Scenario #4 portfolios (round-up values)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_1	1.806	1.000	0.165	2.000	-4.550	0.511	-4.039
P_2	1.806	1.000	0.193	2.461	-4.740	0.414	-4.326
P_3	1.806	1.000	-0.074	1.500	-4.651	0.425	-4.226
P_4	1.806	1.000	0.100	3.461	-5.378	0.032	-5.346
P_5	1.806	1.000	-0.138	2.500	-5.246	n.a	n.a
P_6	1.806	1.000	-0.033	2.961	-5.322	n.a	n.a
P_7	1.806	1.000	-0.194	3.961	-6.059	n.a	n.a
P_8	2.059	1.461	0.314	2.461	-4.660	0.461	-4.199
P_9	2.059	1.461	0.333	2.461	-4.632	0.483	-4.149
P_{10}	2.059	1.461	0.324	1.961	-4.395	0.646	-3.749
P_{11}	2.059	1.461	0.221	3.461	-5.297	0.073	-5.224
P_{12}	2.059	1.461	0.088	2.961	-5.242	0.035	-5.208
P_{13}	2.059	1.461	0.122	2.961	-5.193	0.081	-5.112
P_{14}	2.059	1.461	-0.073	3.961	-5.979	n.a	n.a
P_{15}	2.097	0.500	0.057	1.500	-3.800	1.204	-2.597
P_{16}	2.097	0.500	0.110	1.500	-3.722	1.262	-2.460
P_{17}	2.097	0.500	0.334	1.961	-3.624	1.347	-2.277
P_{18}	2.097	0.500	-0.007	2.500	-4.395	0.749	-3.646
P_{19}	2.097	0.500	0.098	2.961	-4.472	0.736	-3.736
P_{20}	2.097	0.500	0.131	2.961	-4.422	0.781	-3.642
P_{21}	2.097	0.500	-0.063	3.961	-5.208	0.257	-4.951
P_{22}	1.389	2.461	-0.051	3.461	-7.090	n.a	n.a
P_{23}	1.389	2.461	-0.184	2.961	-7.035	n.a	n.a
P_{24}	1.389	2.461	-0.345	3.961	-7.772	n.a	n.a
P_{25}	1.444	1.500	-0.273	2.500	-6.174	n.a	n.a
P_{26}	1.444	1.500	-0.168	2.961	-6.250	n.a	n.a
P_{27}	1.444	1.500	-0.329	3.961	-6.987	n.a	n.a
P_{28}	1.685	1.961	-0.048	2.961	-6.173	n.a	n.a
P_{29}	1.685	1.961	-0.015	2.961	-6.123	n.a	n.a
P_{30}	1.685	1.961	-0.209	3.961	-6.909	n.a	n.a
P_{31}	1.040	2.961	-0.480	3.961	-8.686	n.a	n.a

8.2.3 Performance vs. Value of Flexibility

Figure 133 illustrates the tradeoff that exists between performance (represented here as the average delays due to runway congestion) and the value of flexibility, with each point representing a technology portfolio. In particular, Figure 134 shows that, for a similar or better performance (blue square), the value of flexibility for Scenarios #2, #3 and #4 under *Airport #2* is much higher than under *Airport #1*. This can be explained by the fact that, even though *Airport #2* generates less revenue than *Airport #1*, it is subjected to lower operating costs than *Airport #1*. The information presented in this figure also allows decision-makers to identify portfolios with the highest strategic value among the ones that perform similarly (red oval). Finally, the significant difference in strategic value between portfolios belonging to Scenario #4 when compared to other scenarios (blue and green arrows) is further discussed in Section 8.2.3.2. The impact of the number of technologies considered, as well as that of the timing of the investment, on both performance and flexibility are further discussed in the following sections.

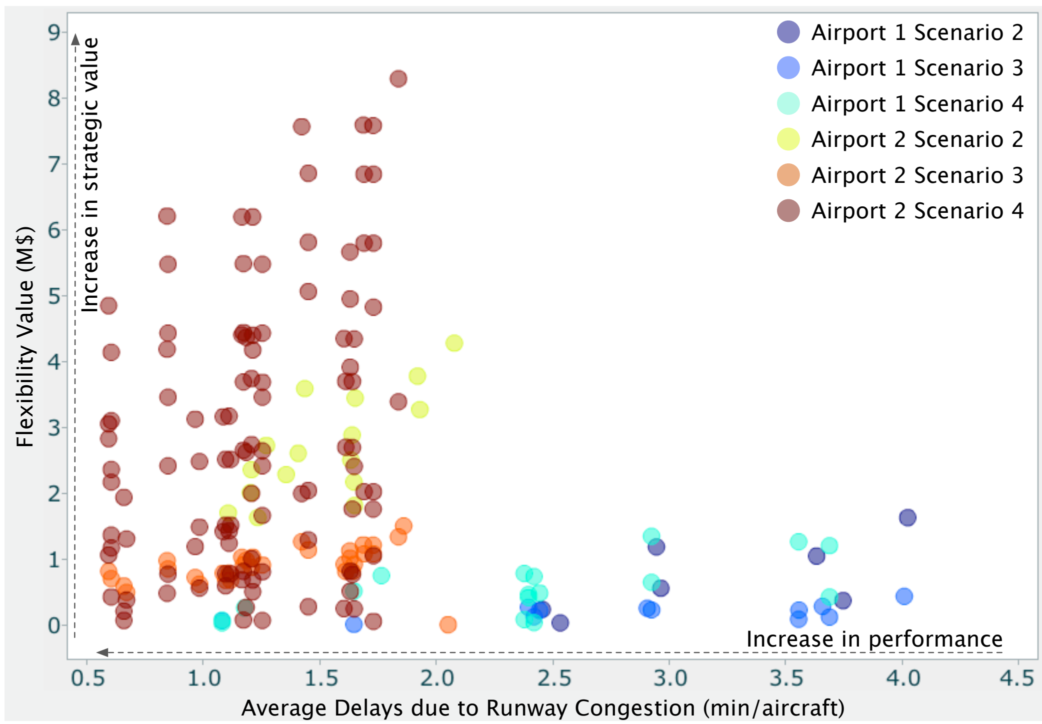


Figure 133: Value of flexibility vs. average delay due to runway congestion for *Airport #1* and *Airport #2* (Scenarios #2, #3, and #4). Only portfolios for which all option values could be computed are represented.

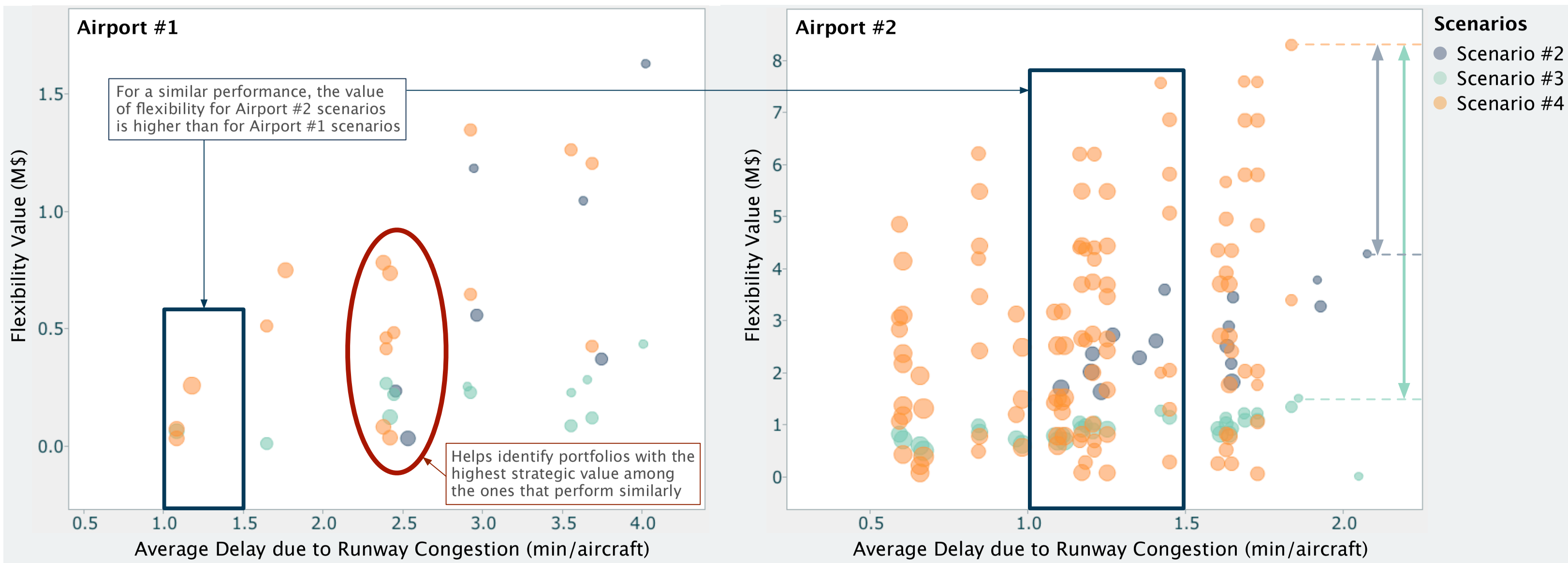


Figure 134: Value of flexibility vs. average delay due to runway congestion for *Airport #1* and *Airport #2* (Scenarios #2, #3, and #4). Only portfolios for which all option values could be computed are represented.

8.2.3.1 *Impact of Portfolio Size*

Figure 135 illustrates how both performance (represented here as the average total delay) and the value of flexibility evolve with the size of the portfolios (in terms of number of technologies included). As expected, performance increases as more technologies are deployed. This, however, happens to the detriment of the value of flexibility. Hence, as the number of technologies in a given portfolio increases, so does the strike price of the option considered, which in turn decreases the value of the option. Finally, Figure 135 helps identify portfolios with the highest strategic value among the ones that perform similarly.

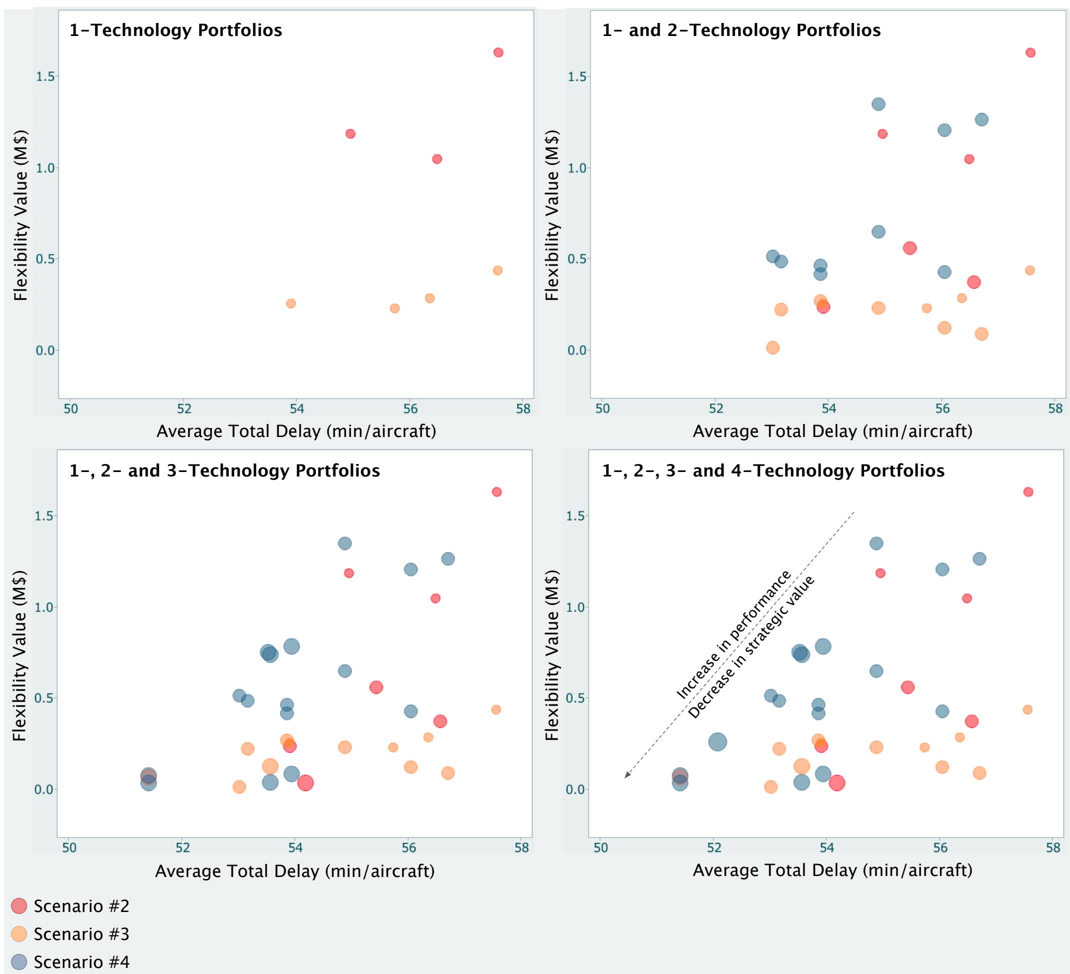


Figure 135: Value of flexibility vs. delay responses for different portfolio sizes.

8.2.3.2 Impact of Investment Timing

Figures 136 and 137 illustrate how both performance and strategic value change with the timing of the investment for *Airport #1* and *Airport #2* (with lighting technology), respectively.

For *Airport #1*:

Figure 136 shows that the best tradeoff between performance and strategic value is achieved under Scenario #4 (sequential investment). This is mainly due to the timing of this scenario which helps address congestion before it becomes critical but at a cost lower than that of a similar portfolio under Scenario #2. Also, this figure further highlights the observation made previously that the strategic value decreases when the investment occurs too far into the future (Scenario #3), as there is not enough time left to alleviate congestion and recover from the costs.

For *Airport #2* with lighting technology:

As previously discussed, this airport is not subjected to congestion. Consequently, the airport revenues across each scenarios remain the same. Hence, the only difference between each scenario lies in the number of technologies included in their corresponding portfolios (i.e. the cost of the portfolios) and the timing of the investment. As illustrated by Figure 137, the same observation can be made for portfolios in Scenario #3 *Airport #2* than for those in Scenario #3 *Airport #1*: the investment occurs too late, in other words, the airport does not have the time to recover from the cost of acquiring technologies. In turn, the difference in strategic value between Scenarios #2 and #4 mainly lies in the costs incurred at Year 5. Hence, these costs are much more important for Scenario #2 (one-time investment) than they are for Scenario #4 (staged investment). Scenario #4 thus offers more flexibility.

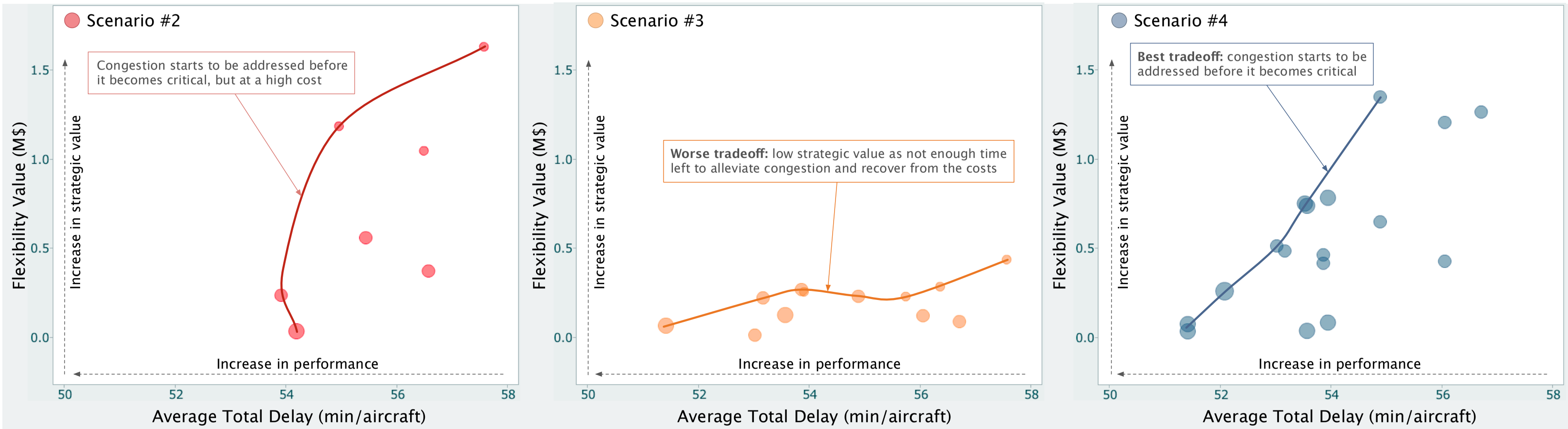


Figure 136: Identification of a pareto front for each investment scenario under *Airport #1* (only portfolios for which all option values could be computed are represented).

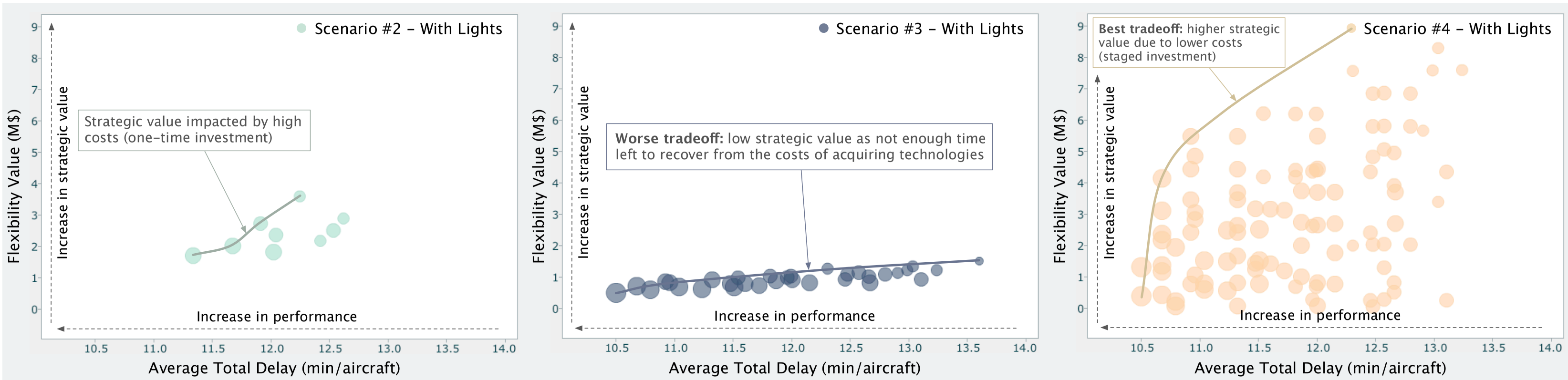


Figure 137: Identification of a pareto front for each investment scenario with lighting under *Airport #2* (only portfolios for which all option values could be computed are represented).

8.2.3.3 Impact of a Lighting System

Figure 138 illustrates the differences in performance and strategic value for portfolios with and without a lighting technology under *Airport #2* Scenarios #2 and #3. For Scenario #2, it shows that despite the difference in performance (due to the difference in levels of traffic) between portfolios with and without a lighting technology, the range of strategic values remain approximately the same. Options with no lighting systems are still valuable because both their stock and strike prices are relatively low (these portfolios have on average 2.13 technologies as opposed to 3 for portfolios that include a lighting system). For Scenario #3, Figure 138 shows that the strategic value of the portfolio without a lighting system is much lower than that with such technology. In this instance, the revenues are too low (due to low levels of traffic) and the costs of the technologies considered too high for this option to be valuable. Hence, investing in a lighting system at Year 5 (Scenario #2) appears as a better alternative, both in terms of performance and strategic value, than doing so at Year 10 (Scenario #3). Figure 139 illustrates the differences in performance and strategic value for portfolios with and without a lighting technology under *Airport #2* Scenarios #4 only. As expected, the portfolios with higher strategic value are the ones that include a lighting technology, as they generate higher revenues.

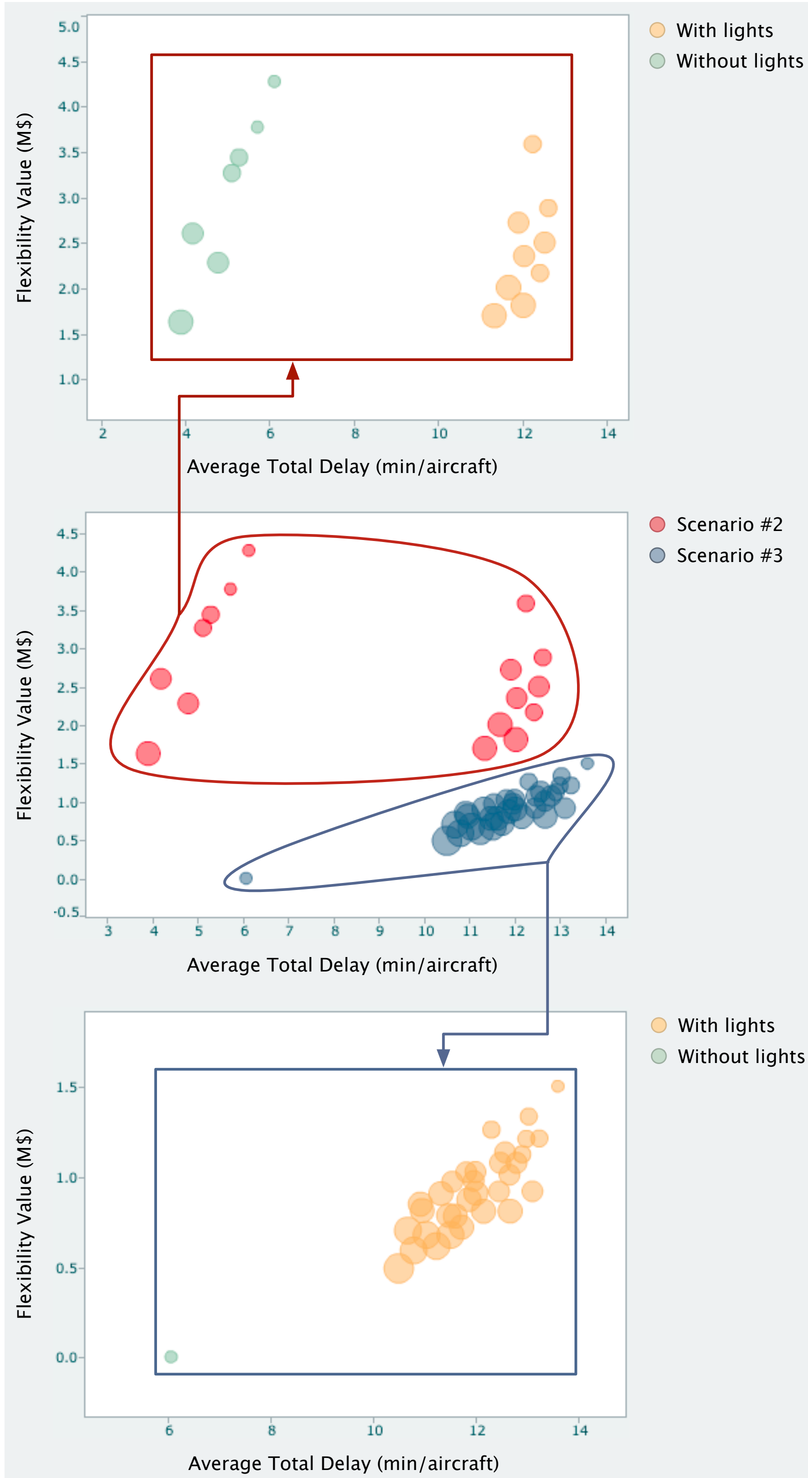


Figure 138: Average total delays and strategic value with and without lighting technology for Scenarios #2 and #3 (only portfolios for which all option values could be computed are represented).

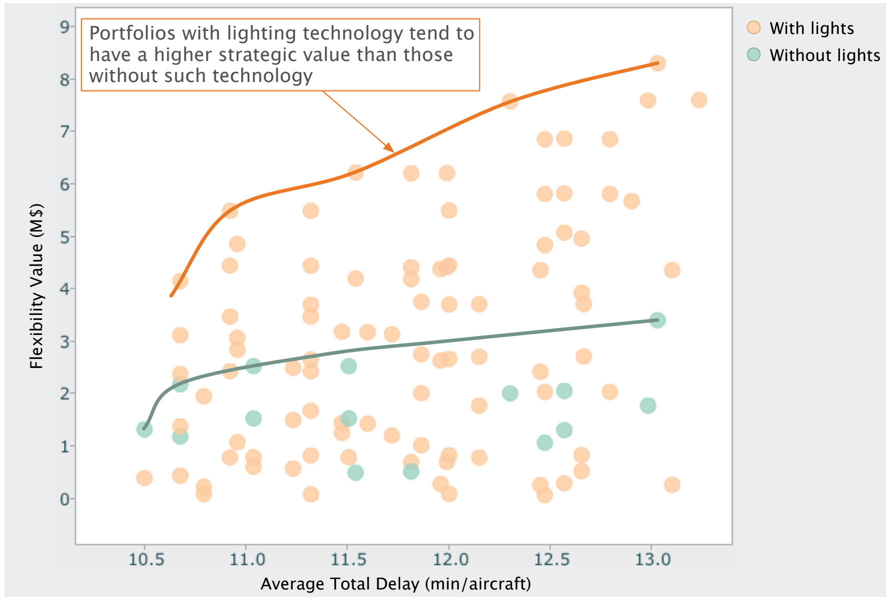


Figure 139: Average total delays and strategic value with and without lighting technology for Scenario #4 (only portfolios for which all option values could be computed are represented).

8.2.3.4 Impact of Investment Sequence

Similar portfolios exist across the investment scenarios considered. Tables G.28 and G.29 in Appendix G summarize these portfolios and their technologies, along with the potential sequence under which they can be deployed (for *Airport #1*). The strategic value of these portfolios for each investment ID is illustrated in Figure 140. As an example, one can decide to invest into both technologies T_{29} and T_3 at once:

- Invest in both technologies at Year 5 (Scenario #2: orange dot in both A & B squares)
- Invest in both technologies at Year 10 (Scenario #3: red dot in both both A & B squares)

or at two distinct points in time (Scenario #4):

- Invest in T_3 at Year 5 and in T_{29} at Year 10 (Scenario # 4: blue dot in square A)
- Invest in T_{29} at Year 5 and in T_3 at Year 10 (Scenario # 4: blue dot in square B)

Figure 140 shows that, under the modeling and cost assumptions made in Section 7.5.1, investing in two technologies sequentially is more valuable strategically than deploying them both at once. However, as illustrated, the sequence under which these investments take place matters significantly. Hence, while the sequence T_3, T_{29} results in a strategic value of M$0.646, the sequence T_{29}, T_3 provides a strategic value of M$1.346. When investing in only two technologies, this work shows that, under the assumptions formulated, investing in the cheapest technology first consistently results in higher strategic value (for *Airport #1*). When investing in 3 technologies, the same observation seems to hold true when the ratio of the costs of the first investment over the costs of the second investments remain below a certain value (for *Airport #1*).

Figure 141 illustrates the impact of the timing of lighting technology deployment on the value of flexibility for *Airport #2* Scenario #4 portfolios that include lighting technology by the end of the timeframe considered. This figure shows that, when investing in only two technologies, investing in the lighting technology first consistently yields higher strategic value. When investing in three technologies, investing in only one technology at Year 5 leads to more valuable portfolios. In particular, investing in T_{21} (lighting technology) first often results in portfolios with higher strategic value. The difference in value between such portfolios then depends on the technologies acquired at Year 10. Hence, the value of flexibility for *Airport #2* Scenario #4 portfolios (with lighting technology) depends on the timing of the deployment of the lighting technology, the technology(ies) acquired at Year 10, and the cost of the investment at Year 5.

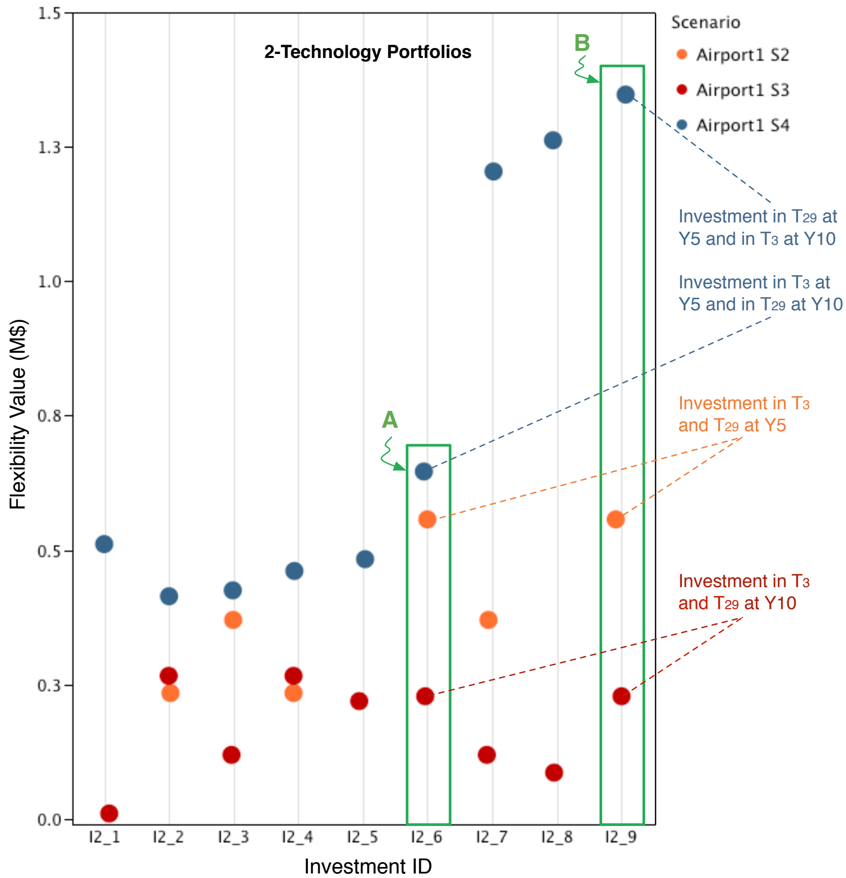


Figure 140: Value of flexibility as a function of the investment sequence and the number of technologies included in *Airport #1* portfolios (only investment IDs for which all option values could be computed are represented).

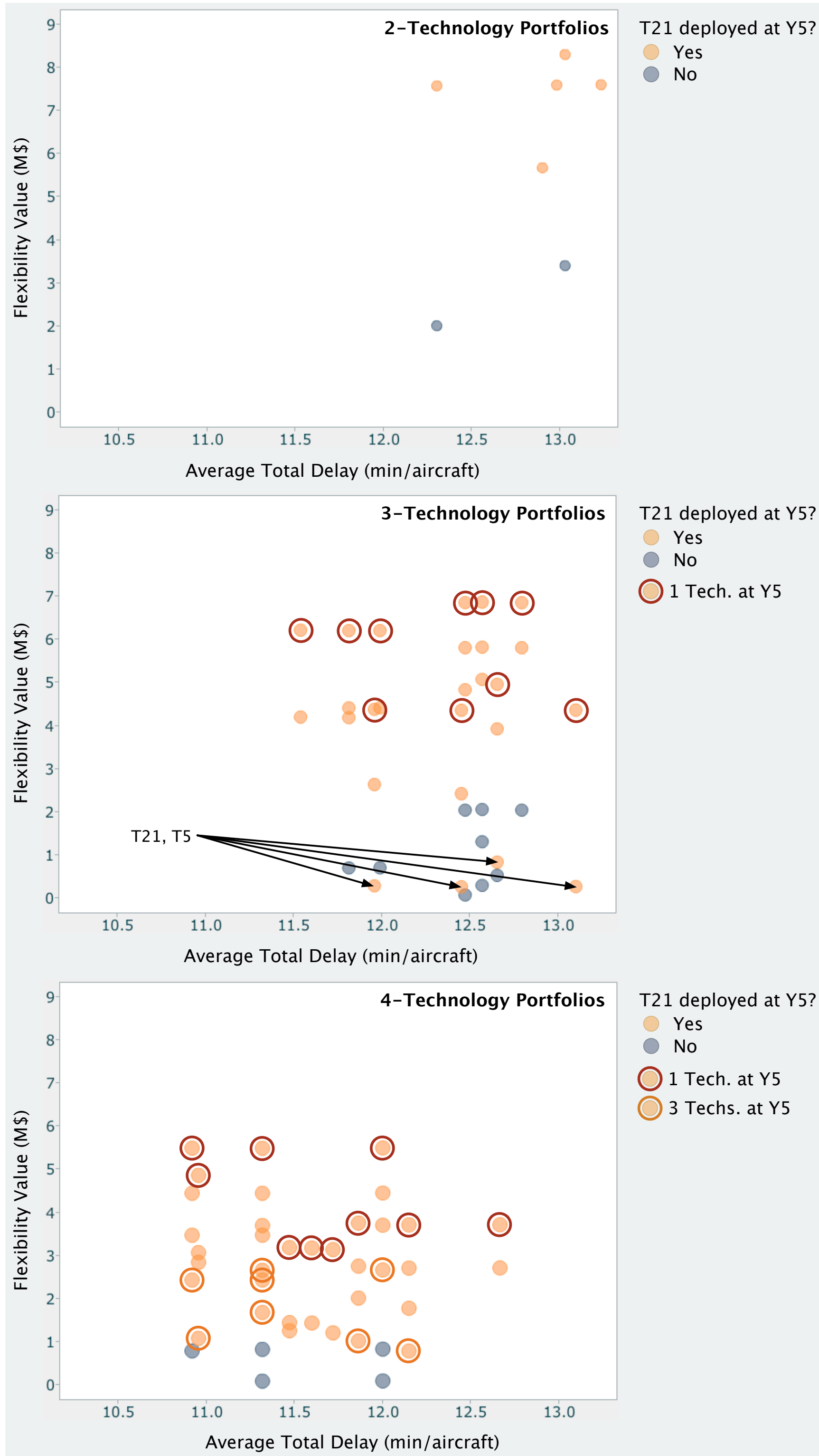


Figure 141: Value of flexibility vs. average total delay (min/aircraft) for different *Airport #2* Scenario #4 portfolio sizes with lighting technology in place by the end of Y15 (only portfolios for which all option values could be computed are represented).

8.2.3.5 *Tradeoff Capabilities*

The implementation of the proposed methodology allows one to quickly assess how portfolios perform across the different performance responses considered for both *Airports #1* and *#2*. It also enables many tradeoffs to be conducted at both portfolio and technology levels. Hence, as illustrated in Figures 142 and 143, portfolios can be filtered according to:

- Technologies: to identify portfolios that only include the technologies the analyst or decision maker is interested in
- Performance constraints/range: to identify portfolios that satisfy specific performance constraints
- Flexibility value/range: to identify the portfolios that provide the set flexibility value/range
- Airport: to identify portfolios specific to a particular airport
- eNPV value: to identify portfolios worth investing in
- Any combination of the above criteria.

Such capability provides a more accurate picture and better understanding of the investment alternatives offered to airport stakeholders.

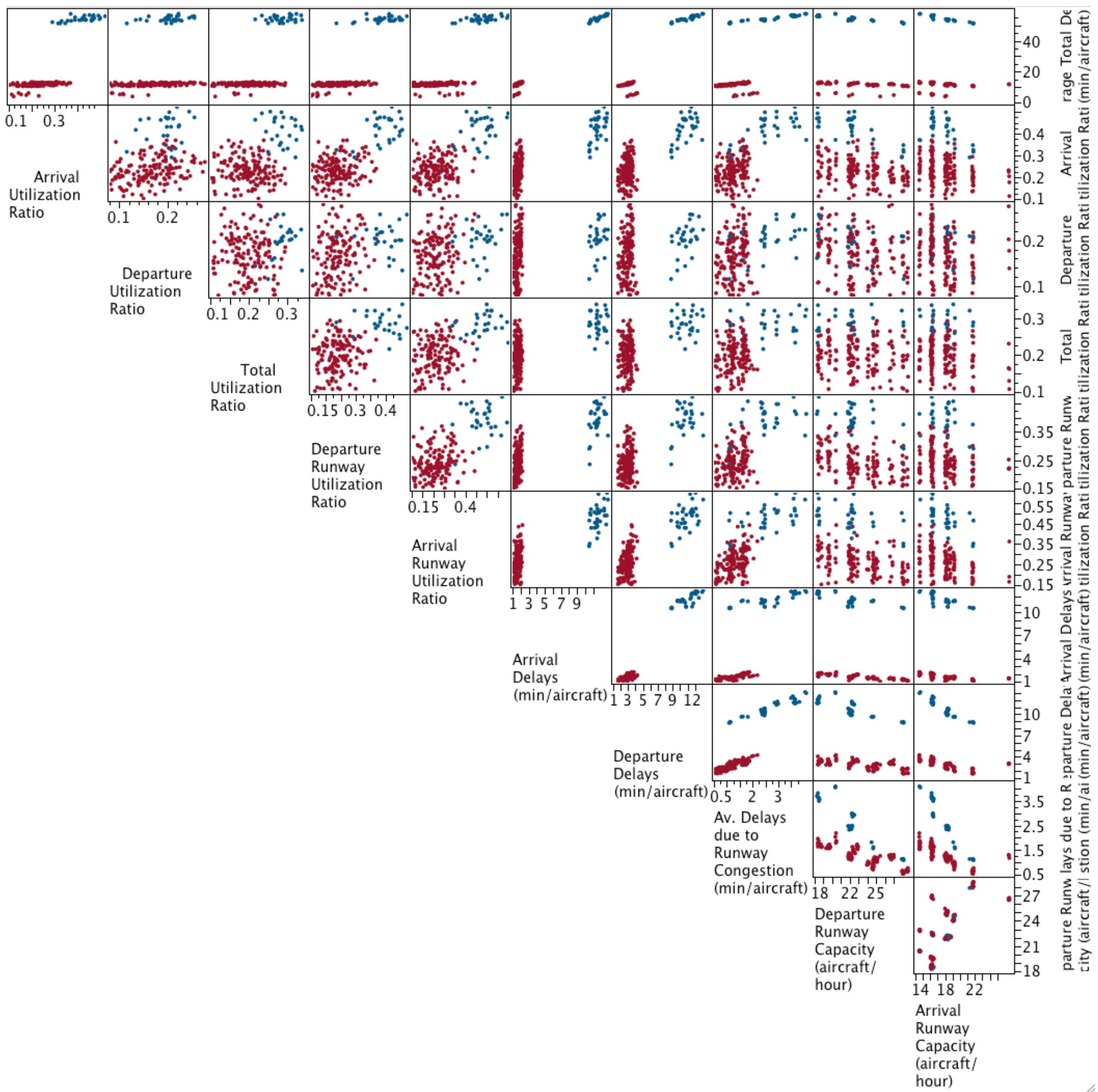


Figure 142: Scatterplot matrix of airport performance indicators (each point corresponds to a portfolio (blue: *Airport #1*, red: *Airport #2*).

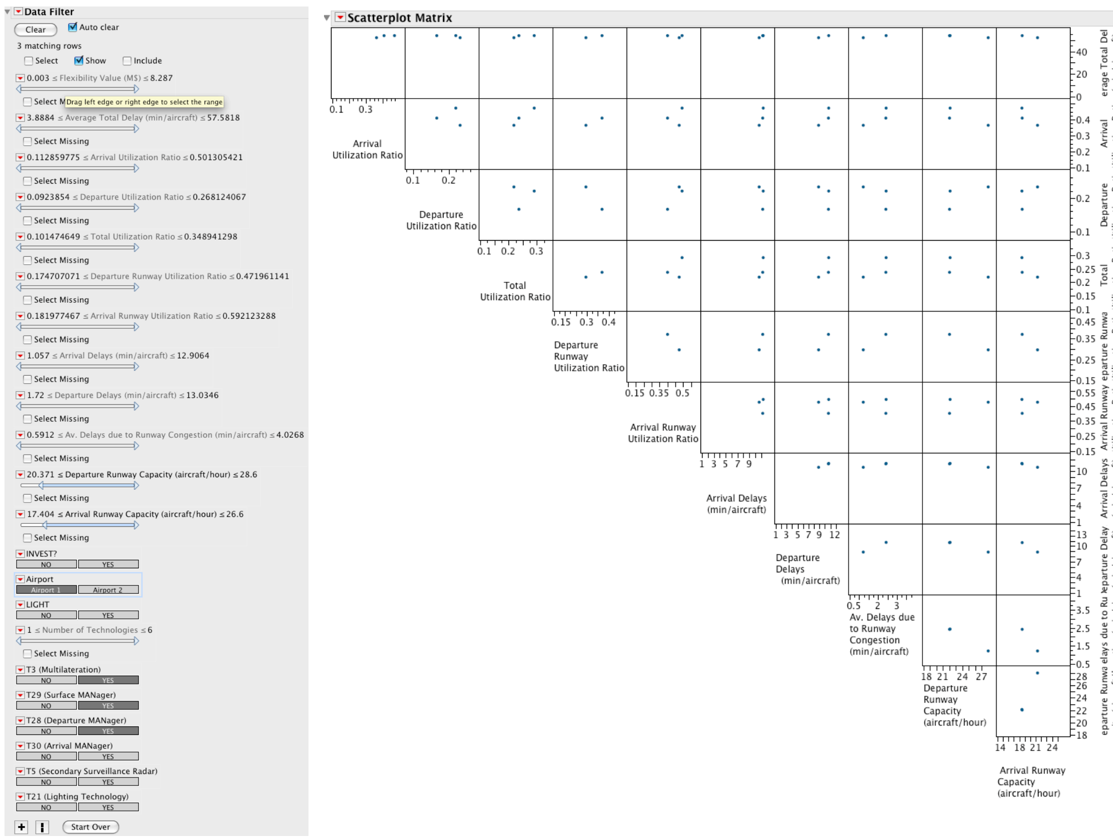


Figure 143: Filtered scatterplot matrix of airport performance indicators.

The following section summarizes the observations made throughout this chapter in the context of Research Questions 3.1 and 3.2., and Hypotheses 3.1 and 3.2.

Research Question 3.1: How do we define and embed flexibility in the formulation of technology portfolios so as to answer airport future requirements and provide financially viable solutions?

Research Question 3.2: What is the strategic value, for airports, of embedding flexibility in the formulation of technology portfolios?

Hypothesis 3.1: The implementation of sequential, or staged, investment decisions, on which airports can decide to leverage earlier investments, will allow airports to meet their future requirements and provide them with financially viable solutions.

Hypothesis 3.2: The strategic value of the flexibility embedded in technology portfolios can be captured through the formulation of sequential nested options and represented as the value of the real option.

8.3 Remarks on the Results from the Performance and Revenue Assessment, and Flexibility Valuation

This work has illustrated that considering both performance and financial indicators concurrently is critical. The following paragraphs provide the main "take-aways" in the context of each airport.

8.3.1 For *Airport #1*

From a performance stand point, this research has shown that implementing sequential investment decisions (Scenario #4) leads to improved performance across all responses.

From a revenue stand point, this research has demonstrated the capacity of staged investments to help delay the effect of congestion on revenues and to generate more revenues during the timeframe considered.

From a flexibility stand point, this research has illustrated the importance of investment timing. In particular, it has shown that Scenario #4 portfolios (sequential investment) often provide the most value, but that attention should be paid as to which technology to acquire first

8.3.2 For *Airport #2*

From a performance stand point, this research has demonstrated that performance improvements due to staged investments (Scenario #4) in the context of this airport are relatively small when compared to the ones obtained from following a one-time investment scenario (Scenario #2).

From a revenue stand point, this work has illustrated that the benefits on revenues stemming from implementing a sequential investment are small when compared with revenues from Scenario #2.

From a flexibility stand point, this research has shown that there is little difference in value between investment scenarios when the level of traffic is too low. However, when the traffic is sufficient, a sequential investment scenario becomes much more valuable than a one-time-only investment scenario. Finally, this work has illustrated that, in the case of sequential investments, investing in lighting technology early on generally results in portfolios having a higher strategic value.

In light of these observations, it appears that **Hypothesis 3.1, while verified for *Airport #1*, cannot be generalized to all airports**. In particular, the level of traffic seems to have an impact on the applicability of this hypothesis. Hence, airports with low levels of traffic may not be as sensitive to the type of investment scenarios (one-time vs. sequential investment) as airports with higher levels of traffic. Airports with a sufficient level of traffic, on the other hand, may significantly benefit, in both performance and strategic value, from implementing sequential investment scenarios.

This work has demonstrated the importance of accounting for managerial flexibility when considering investment projects. In particular, this research has illustrated that, by accounting for both the static NPV and the value of the option, the eNPV criterion provides a means to capture the value of active decision making and future investment opportunities. Hence, through the use of Real Options Analysis, this work enables the quantitative assessment of the strategic value of embedding flexibility in the formulation of technology portfolios and investment options. By doing so, it provides a better picture and more complete assessment of the investment alternatives available to airport stakeholders. In light of this discussion and the results provided, **Hypothesis 3.2 is verified.**

8.3.3 Generalization

This research has illustrated that the difference in value between investment scenarios depends on:

- The level of traffic at the airport: low traffic generates revenues that are too low to offset the cost of acquiring technologies
- The presence or not of congestion: congestion has an impact on revenues and thus on the ability of the airport to recover from technology acquisition costs
- The timing and sequence of the investment: late investments often come too late or are too costly to allow the airport to recover
- The number of technologies to be acquired: the better the performance, the lower the value of flexibility. In other words, better performance comes at a cost, which corresponds to a decrease in the strategic value of the investment decision

More importantly, this work has shown that the best technology portfolio under the best investment timing will not allow airport to meet their future requirements if the necessary ground infrastructure is insufficient. This supports the statement made in Section 1.4 that improvements in airport performance will come from considering and implementing a combination of solutions and strategies.

CHAPTER IX

CONCLUSIONS

This research focused on the implementation of operational concepts and technologies at small and medium airports as a means to address the increase in demand and resulting capacity issues currently experienced in the air transportation system. As discussed throughout this document, there are many challenges associated with sustaining the development of this type of airports. In particular, the need to synchronize evolving technologies with airports' needs and investment capabilities was recognized as being an important one. Additionally, it was observed that the evolution of secondary airports, and their needs, are tightly linked to the environment in which they operate. In particular, sensitivity of airports to changes in the dynamics of their environment was emphasized, and the necessity to identify the factors that drive the need for technology acquisition was acknowledged. Finally, the difficulty to evaluate risk and make financially viable decisions, particularly when investing in new technologies, was recognized. More importantly, the potential benefits of providing the capability to adapt to evolving circumstances as a way to mitigate risk and address uncertainty were discussed.

Based on these observations, a four-step methodology has been implemented that leverages the benefits yielded by impact assessment techniques, system dynamics modeling, and real options analysis to 1) provide the decision maker with a rigorous, structured, and traceable process for technology selection, 2) assess the combined impact of interrelated technologies, 3) support the translation of technology impact factors into airport performance indicators, and help identify the factors that drive the need for capacity expansion, and finally 4) enable the quantitative assessment of the strategic value of embedding flexibility in the formulation of technology portfolios and investment options. Hence, the first step of the methodology, which is to identify and define the technology space of interest to decision makers, has been shown to be successfully supported by the implementation of relevance tree analysis, morphological analysis, filters and dependency tables.

Second, the need to identify technology relationships to further assess their combined impact has, in turn, highlighted the limited applicability of Cross Impact Analysis for the problem at hand. In particular, this research has illustrated that results provided by CIA are sensitive to the number of technologies considered. Consequently, the limited number of technologies studied in this work strongly impacts the robustness of the information CIA provides. The lack of consistency in the descriptions of the technologies, along with the disparate level of detail and information within both NextGen and SESAR programs, have also been shown to limit the proper identification of technology relationships using this approach. Being able to highlight this lack of consistency, however, can be useful for future harmonization efforts between NextGen and SESAR.

Third, the integration of the airport and System Dynamics models developed for this work was shown to provide the necessary environment and level of abstraction to characterize the nature (demand or technological) of the key factors that drive the need for capacity expansion, and to differentiate between them. In particular, the two consecutive sensitivity analyses conducted on the models have pointed out that, as expected, the need for capacity expansion is mostly driven by traffic/demand variables. However, they have also shown that this need can be addressed, at the technological level, with technologies having an impact on departure operations and minimum separation between arriving and departing aircraft.

Finally, the use of Real Options Analysis has made possible the quantitative assessment of the strategic value of embedding flexibility in the formulation of technology portfolios and investment options. This methodology has demonstrated, through a change in demand at the airport modeled, the importance of being able to weigh both the technological and strategic performance of the technology portfolios considered. In particular, it has illustrated the impact that the level of traffic, the presence of congestion, the timing and sequence of investments, and the number of technologies included, have on the strategic value of a portfolio. Hence, by capturing the time dimension and technology causality impacts in technology portfolio selection, this work has helped identify key technologies or technology groupings, and assess their performance on airport metrics. By embedding flexibility in the formulation of investment scenarios, it has provided the decision maker with a more accurate picture of the options available to him, as well as the time and sequence under which these should be exercised.

A methodology can be judged on many grounds, such as parsimoniousness and adequacy, as well as from the perspective of its extensibility or relevance to similar problems of interest. However, those criteria may sometimes appear as conflicting. Hence, efforts to develop a "simpler" methodology may eventually limit its applicability to other problems. Similarly, as a parallel to Mach's theory [205], one could evaluate the goodness of a methodology based on its ability to answer the maximum number of questions with the least modeling or mental effort. Consequently, justifying the ability of this methodology to meet each one of these criteria is difficult, if not impossible, as it is highly relative but also extends beyond the methodology itself. As discussed by Beck [24], "what appears suitable at a given time will depend in part upon the 'intellectual climate,' the scientific environment, and the character of the scientific thinker." Others can also argue that a methodology presents the appropriate level of sophistication if it is comprehensible to the user and allows him to obtain correct and useful answers with an acceptable amount of time and effort.

Significant efforts have been made, throughout this research, to develop a methodology that enables the substantiation of the hypotheses formulated in the first chapters. In addition, the steps included in this methodology can be directly mapped to the ones commonly used in the formulation of generic top-down design decision support processes. As such, the general approach followed in this work is widely applicable to problems where technologies have to be identified, assessed and where eventually decisions have to be made regarding which one(s) to select. However, while this methodology is universal for this type of problem, it is unique in its implementation and the tools chosen.

Indeed, the scope, context, as well as the nature, granularity and complexity of the trades to be conducted have helped define the steps of the methodology. They have also guided the choice of techniques and modeling environments to be integrated within each of these steps. For example, the very nature of the technologies considered in this work (technologies that are interrelated, bring different benefits to airports, and are available at different points in time) has motivated the need to decompose the problem. This has, in turn, driven the choice and further integration of techniques such as relevance tree analysis, morphological analysis, etc. Hence, applying this methodology to a problem for which technologies are mutually exclusive and impact the same metric would not require the use of such techniques in the first step of the methodology. Along the same line, applying the present methodology to a wider scope, by also considering the landside component of the airport, for example, would require modifications at the modeling & simulation environment level. In particular, models of landside operations could be integrated to the existing environment and the System Dynamics model extended to capture multi-modal options. Similar to what has been done in this research, previous System Dynamics studies on landside operations could be compiled to help select the variables to be included. Depending on the level of detail necessary to support informed decision making, passenger loads could be added to the existing model to capture the level of passenger traffic going through the airport's terminals. Similarly to airport ground technologies, technologies related to landside operations could be included, and their causal impact captured, to provide stakeholders with an assessment of portfolios that combined both airside and landside technologies.

Fully validating the present methodology for this problem and other similar problems is mostly impossible, because 1) the scenarios considered cannot be predicted/observed realistically within the timeframe of this research, 2) the resulting portfolios, and their combinations, cannot be individually implemented and compared at a single airport, and 3) significant uncertainty exists as to the performance and availability of the technologies considered. Hence, in this context, validation efforts have been focussing on making sure that the models are being used correctly and that the results obtained depict what could be expected in reality. At the airport modeling level, efforts to validate the present work include the use of an airside model, MACAD, which has previously been validated, and which has been praised by the community for its capabilities. In addition, steps have been taken to calibrate the airport model with real data to ensure that the traffic modeled is representative of that of the airport, and that the results obtained are within realistic bounds. Systems Dynamics models, as discussed by Sterman, are impossible to validate. However, efforts have been carried to ensure that each equation in the model satisfies dimensional consistency and is a good representation of the relationship(s) being modeled. In addition, the model has been tested and sensitivity analyses conducted to ensure that its behavior properly captures that of the actual system. Finally, data available from the literature has been used, as relevant, to document the technologies' performance and costs. Finally, the results obtained from implementing this methodology have been carefully examined to make sure that they were sensible.

Fully validating this methodology could hypothetically be made possible by comparing its results with those from the acquisition history and performance of an airport. This would in turn require modeling existing technologies only, as opposed to future technologies. Such validation would thus necessitate to have detailed traffic (flights schedules, type and number of aircraft, number of arrivals and departures, arrival and departure taxi averages, time spent at the gate for each individual aircraft, inter-departure and approach separations, approach speeds, etc.) and financial data (operating costs, etc.) for the airport and time frame under consideration. Data relative to airport performance, in terms of capacity and delay, would also be essential. In particular, delay information should identify delays that are under the airport's control from delays due to external factors (weather, ground delay at an other airport, airlines tactical decisions, maintenance issues, etc.). Full validation would also require to model the technologies considered for investment by this airport during that time frame. As such, data regarding the costs of each technology and their performance on each metric of interest should be fully documented and available. Information as to when investment decisions were made and which technologies were selected should also be reported. However, supposing that all the necessary data is collected and available, this methodology could only be validated for one scenario and one particular subset of technologies (the ones the airport invested in). Hence, one would have to assume that, if this methodology is valid in this particular instance, it is also valid for the additional technologies and scenarios it considers. Another means to help validate this methodology could thus consist in simplifying the problem and/or model. This would involve limiting the number of technologies (only assessing technologies that have an impact on surveillance, for example), reducing the number of impact metrics considered, and/or the number of variables included in the airport model (removing approach speed variables, for example).

9.1 Research Contributions

The contributions of this research stem from the need to address the different observations and research questions formulated throughout this document. These contributions are academically rigorous and reproducible, as well as practical and valuable for the user of this methodology.

One challenge of this work was to identify technologies of interest to airports. Hence, by providing a rigorous, structured, and traceable process for technology identification and selection, this research helps understand technologies in the context of airport needs, as well as in the broader context of NextGen and SESAR. The decomposition proposed, not only allows airport stakeholders to better grasp the technology options available to them, but also supports the community's understanding of these programs [254] and the future in which airports will have to operate. In addition, the integration of this process with the visual capabilities used and developed in this work, allows the user to quickly compare, analyze and synthesize information at all levels, in a way that was not available before.

Previous work focussing on technology evaluation and selection often assumed the independence of technologies when assessing their combined impact. This work proposed to eliminate this assumption by accounting for technology relationships in such an assessment. As such, this research provides a better and more realistic representation of the impact of technologies on the system.

Previous work has also acknowledged and emphasized the importance of considering flexible investment strategies. However, the alternatives to airport strategic planning that have been recently proposed lack the capability to capture the key factors that drive the need for capacity expansion. While this work has been conducted on a limited number of factors, it has demonstrated the capability of the proposed approach to provide an integrated framework that supports sensitivity analyses at both system and technological levels.

Finally, while many airport performance studies have been realized, they often conduct performance assessment in isolation of strategic considerations. The present research recognizes that investing in technologies cannot be solely based upon performance evaluation. As such, this work provides a quantitative assessment of both portfolio performance and strategic value to provide airport stakeholders with a more complete picture of the investment alternatives available to them. Previous airport studies that do address the need for flexible strategies often apply Real Options Analysis to infrastructure expansion problems (building a second runway, buying adjacent land, etc). This work, on the other hand, applies Real Options Analysis to the problem of technology acquisition. Considering technology portfolios as investment options brings additional complexity and challenges:

- There is now a need to identify and integrate the nature of technology relationships when assessing their impact

- There is a need to account for technology availabilities in the formulation of options

- More investment scenarios and options need to be investigated than when compared to the traditional "go-no go" option studied in previous work

As such, the proposed method allows analysts and decision makers to quantitatively assess and understand the impact that the number of technologies, as well as the timing and sequence of investments, have on both the performance and strategic value of the alternatives considered. Finally, while previous airport studies using Real Options Analysis looked at the impact that various levels of additional capacity (brought by a second runway) would have on the value of flexibility, they did assume a percentage increase in capacity as opposed to calculating it (as done in this work). By doing so, they assumed that this added capacity was unconstrained. As such, they failed to realize that the airport ground infrastructure could become the constraining factor, i.e. that additional capacity brought by improvements at the runway level, for example, could be offset by a lack of adequate ground infrastructure (insufficient number of gates, etc.). This research has shown that such consideration is essential, as it eventually has an impact of the value of flexibility for the options considered.

9.2 Recommendations for Future Work

The main limitation of this work stems from the significant amount of time required to run each portfolio. As previously discussed, this makes it difficult to rapidly study the impact of a high number of technologies and eventually limits the types and numbers of tradeoff analyses that this methodology would otherwise enable. One approach attempted to address this issue was to create a surrogate model (model of a model) of MACAD and to integrate the resulting response equations into the System Dynamics model. However, MACAD represents a stochastic process, which means that similar inputs result in different outputs and building a surrogate for such a process is known to be particularly difficult. Different surrogate modeling techniques and Design of Experiments (DOEs) have been tested to obtain an acceptable model representation error but to no avail (Appendix H).

Hence, this work could strongly benefit from ongoing research efforts to build surrogates of stochastic models.

One of the main assumptions of this work is that the functionalities and capabilities of the technologies considered are fully achievable. The underlying assumption is that aircraft are fully equipped and cooperating with these technologies. Hence, future work could discard this assumption and study how the diffusion, adoption, or substitution of airborne technologies impact the overall performance of airport operations.

Finally, this research and its conclusions could be extended by varying some of the parameters and factors used in the modeling environment. In particular, one could investigate the impact of improved levels of infrastructure (additional gates, etc.) on airport performance, and technology investment timing and sequence. This would extend the use of the methodology to include some ground side concerns providing a more complete picture of the airport investment strategy.

APPENDIX A

COMPARISON OF SELECTED NEXTGEN AND SESAR IMPROVEMENTS

Table A.1: Comparison of selected NextGen and SESAR improvements

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0307: Integrated Arrival/Departure Airspace Management	2018	**L07-03 TS-0301:** Integrated Arrival Departure Management for Full Traffic Optimization, Including within the TMA Airspace	2020-2025
		L07-02 TS-0302: Departure Management from Multiple Airports	2013-2018
		L07-02 TS-0303: Arrival Management into Multiple Airports	2015-2020
		L07-03 TS-0304: Integrated Arrival/Departure Management in the Context of Airports with Interferences (other local/regional operations	2015-2020
		L10-04 DCB-0303: Improved Operations at Airport in Adverse Conditions using ATFCM Techniques	2010-2016
		L10-03 AO-0501: Improved Operations in Adverse Conditions through Airport Collaborative Decision Making	2007-2013
OI-0309: Use Optimized Profile Descent	2010	**L02-08 AOM-0701:** Continuous Descent Approach (CDA)	2007-2013
		L02-08 AOM-0702: Advanced Continuous Descent Approach (ACDA)	2013-2017
		L02-08 AOM-0704: Tailored Arrival	2015-2018

Table A.2: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0310: Improved GA Access to Traverse Terminal Areas	2018	NA	
OI-0311: Increased Capacity and Efficiency Using RNAV and RNP	2010	**L02-07 AOM-0601:** Terminal Airspace Organization Adapted through Use of Best Practice, PRNAV and FUA where Suitable	2007-2012
		L02-07 AOM-0602: Enhanced Terminal Airspace with Curved/Segmented Approaches, Steep Approaches and RNAV Approaches where Suitable	2011-2017
		L02-07 AOM-0603: Enhanced Terminal Airspace for RNP-based Operations	2015-2020
		L10-02 AOM-0404: Optimized Route Network using Advanced RNP1	2015-2020
		L07-01 TS-0102: Basic Arrival Management Supporting TMA Improvements (incl, CDA, P-RNAV)	2007-2015
OI-0316: Enhanced Visual Separation for Successive Approaches	2012	**L10-07 AUO-0502:** Enhanced Visual Separation on Approach (ATSA-VSA)	2012-2017

Table A.3: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0317: Low Visibility/Ceiling Approaches Operations	2015	**L10-06 AUO-0403:** Enhanced Vision for the Pilot in Low Visibility Conditions	2013-2018
		L10-06 AUO-0404: Synthetic Vision for the Pilot in Low Visibility Conditions	2020-2025
		L10-06 AO-0504: Improved Low Visibility Runway Operations	2008-2013
		L10-06 AO-0505: Improved Low Visibility Runway Operations using GNSS/GBAS	2013-2018
OI-0318: Current Tactical Management of Flow in the En Route for Arrivals/Departures	2008	NA	

Table A.4: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0320: Initial Surface Traffic Management	2014	**L07-02 TS-0201:** Basic Departure Management (DMAN)	2007-2013
		L07-02 TS-0202: Departure Management Synchronized with Pre-Departure Sequencing	2013-2020
		L07-02 TS-0203: Integration of Surface Management Constraint into Departure Management	2014-2018
		L07-02 TS-0306: Optimized Departure Management in the Queue Management Process	2015-2019
		L10-02 AO-0205: Automated Assistance to Controller for Surface Movement Planning and Routing	2013-2017
		L10-02 AO-0207: Surface Management Integrated with Departure and Arrival Management	2013-2017
		L10-03 AO-0501: Improved Operations in Adverse Conditions through Airport Collaborative Decision Making	2007-2013
		L10-03 AO-0602: Collaborative Pre-Departure Sequencing	2010-2016

Table A.5: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0321: Enhanced Surface Traffic Operations	2018	**L10-01 AO-0201:** Enhanced Ground Controller Situational Awareness in All Weather Conditions	2012-2021
		L10-02 AO-0203: Guidance Assistance to Airport Vehicle Driver	2012-2017
		L10-02 AO-0204: Airport Vehicle Driver's Traffic Situational Awareness	2013-2017
		L10-02 AO-0205: Automated Assistance to Controller for Surface Movement Planning and Routing	2013-2017
		L10-02 AO-0206: Enhanced Guidance Assistance to Airport Vehicle Driver Combined with Routing	2013-2017
		L10-02 AO-0207: Surface Management Integrated with Departure and Arrival Management	2013-2017
		L10-03 AO-0601: Improved Turn-Round Process through Collaborative Decision Making	2010-2016
		L08-03 AUO-0401: Air Traffic Situational Awareness (ATSAW) on the Airport Surface	2012-2018
		L10-02 AUO-0602: Guidance Assistance to Aircraft on the Airport Surface	2013-2020
		L10-02 AUO-0603: Enhanced Guidance Assistance to Aircraft on the Airport Surface Combined with Routing	2013-2020

Table A.6: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0321: Enhanced Surface Traffic Operations (Continued)	2018	**L10-02 AUO-0604:** Enhanced Trajectory Management through Flight Deck Automation Systems	2018-2023
		L06-01 CM-0203: Automated Flight Conformance Monitoring	2008-2016
OI-0322: Low-Visibility Surface Operations	2018	**L10-06 AO-0502:** Improved Operations in Low Visibility Conditions through Enhanced ATC Procedures	2009-2015
		textbfL10-06 AO-0503: Reduced ILS Sensitive and Critical Areas	2008-2015
		L10-06 AO-0504: Improved Low Visibility Runway Operations	2008-2013
		L10-06 AO-0505: Improved Low Visibility Runway Operations Using GNSS/GBAS	2013-2018
		L08-03 AUO-0401: Air Traffic Situational Awareness (ATSAW) on the Airport Surface	2012-2018
		L10-06 AUO-0403: Enhanced Vision for the Pilot in Low Visibility Conditions	2013-2018

Table A.7: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0325: Time Based Metering Using RNAV and RNP Route Assignments	2014	**L07-01 TS-0102:** Basic Arrival Management Supporting TMA Improvements (incl, CDA, P-RNAV)	2007-2015
		L07-01 TS-0103: Controlled Time of Arrival (CTA) Through Use of Datalink	2016-2019
		L10-05 AO-0302: Basic Time Based Separation for Final Approach	2012-2015
		L10-02 AOM-0404: Optimized Route Network using Advanced RNP1	2015-2020
		L02-07 AOM-0603: Enhanced Terminal Airspace for RNP-based Operations	2015-2020
OI-0326: Airborne Merging and Spacing - Single Runway	2014	**L08-04 TS-0105:** ASAS Sequencing and Merging as Contribution to Traffic Synchronization in TMA (ASPA-S&M)	2013-2017
		L08-04 TS-0107: ASAS Manually Controlled Sequencing and Merging	2013-2020
		L07-03 TS-0301: Integrated Arrival Departure Management for Full Traffic Optimization, including within the TMA Airspace	2020-2025
		L08-05 CM-0704: Self Separation in Mixed Mode	2025-2035

Table A.8: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0327: Full Surface Traffic Management with Conformance Monitoring	2018	**L10-01 AO-0201:** Enhanced Ground Controller Situational Awareness in All Weather Conditions	2012-2021
		L10-02 AO-0203: Guidance Assistance to Airport Vehicle Driver	2012-2017
		L10-02 AO-0204: Airport Vehicle Driver's Traffic Situational Awareness	2013-2017
		L10-02 AO-0205: Automated Assistance to Controller for Surface Movement Planning and Routing	2013-2017
		L10-02 AO-0206: Enhanced Guidance Assistance to Airport Vehicle Driver Combined with Routing	2013-2017
		L10-02 AO-0207: Surface Management Integrated with Departure and Arrival Management	2013-2017
		L10-03 AO-0602: Collaborative Pre-Departure Sequencing	2010-2016
		L10-03 AO-0603: Improved De-icing Operation through Collaborative Decision Making	2010-2016
		L08-03 AUO-0401: Air Traffic Situational Awareness (ATSAW) on the Airport Surface	2012-2018
		L10-02 AUO-0602: Guidance Assistance to Aircraft on the Airport Surface	2013-2020
		L10-02 AUO-0603: Enhanced Guidance Assistance to Aircraft on the Airport Surface Combined with Routing	2013-2020

Table A.9: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0327: Full Surface Traffic Management with Conformance Monitoring (Continued)	2018	**L10-01 DCB-0301:** Improved Consistency between Airport Slots, Flight Plans and ATFM Slots	2012-2015
		L06-01 CM-0203: Automated Flight Conformance Monitoring	2008-2016
		L07-02 TS-0201: Basic Departure Management (DMAN)	2007-2013
		L07-02 TS-0202: Departure Management Synchronized with Pre-Departure Sequencing	2013-2020
		L07-02 TS-0203: Integration of Surface Management Constraint into Departure Management	2014-2018
		L07-03 TS-0301: Integrated Arrival Departure Management for Full Traffic Optimization, including within the TMA Airspace	2020-2025
		L07-02 TS-0306: Optimized Departure Management in the Queue Management Process	2015-2019

Table A.10: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0331: Improved Management of Arrival/ Surface/Departure Flow Operations	2018	**L10-02 AO-0207:** Surface Management Integrated with Departure and Arrival Management	2013-2017
		L10-04 AO-0402: Interlaced Take-off and Landing	2008-2016
		L10-04 AO-0403: Optimized Dependent Parallel Operations	2012-2015
		L10-03 AO-0602: Collaborative Pre-Departure Sequencing	2010-2016
		L10-04 DCB-0303: Improved Operations at Airport in Adverse Conditions using ATFCM Techniques	2010-2016
		L07-01 TS-0102: Basic Arrival Management Supporting TMA (Improvements incl, CDA, P-RNAV)	2007-2015
		L07-01 TS-0103: Controlled Time of Arrival (CTA) Through Use of Datalink	2016-2019
		L07-01 TS-0104: Integration of Surface Management Constraint into Arrival Management	2014-2017
		L07-02 TS-0201: Basic Departure Management (DMAN)	2007-2013
		L07-02 TS-0202: Departure Management Synchronized with Pre-Departure Sequencing	2013-2020
		L07-02 TS-0203: Integration of Surface Management Constraint into Departure Management	2014-2018

Table A.11: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0331: Improved Management of Arrival/Surface/Departure Flow Operations (Continued)	2018	**L07-03 TS-0301:** Integrated Arrival Departure Management for Full Traffic Optimization, Including within the TMA Airspace	2020-2025
		L07-02 TS-0302: Departure Management from Multiple Airports	2013-2018
		L07-02 TS-0303: Arrival Management into Multiple Airports	2015-2020
		L07-03 TS-0304: Integrated Arrival/Departure Management in the Context of Airports with Interferences (other local/regional operations	2015-2020
		L07-01 TS-0305: Arrival Management Extended to En Route Airspace	2010-2017
		L07-02 TS-0306: Optimized Departure Management in the Queue Management Process	2015-2019
OI-0333: Improved Parallel Runway **OI-0333:** Operations	2016	**L10-04 AO-0403:** Optimized Dependent Parallel Operations	2012-2015
OI-0334: Independent Converging Approaches in IMC	2017	NA	

Table A.12: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0338: Efficient Metroplex Merging and Spacing Operations	2020	**L10-05 AO-0303:** Fixed Reduced Separations Based on Wake Vortex Prediction	2013-2020
		L10-05 AO-0304: Dynamic Adjustment of Separations Based on Real-Time Detection of Wake Vortex	2015-2019
		L07-01 TS-0103: Controlled Time of Arrival (CTA) Through Use of Datalink	2016-2019
		L07-01 TS-0106: Multiple Controlled Times of Over-fly (CTOs) Through Use of Data Link	2018-2023
OI-0339: Integrated Arrival/Departure and Surface Traffic Management for Metroplex	2022	**L07-02 TS-0302:** Departure Management from Multiple Airports	2013-2018
		L07-02 TS-0303: Arrival Management into Multiple Airports	2015-2020
		L07-03 TS-0304: Integrated Arrival/Departure Management in the Context of Airports with Interferences (other local/regional operations	2015-2020
		L07-02 TS-0306: Optimized Departure Management in the Queue Management Process	2015-2019
		L10-04 DCB-0303: Improved Operations at Airport in Adverse Conditions using ATFCM Techniques	2010-2016
		L10-03 DCB-0304: Airport CDM extended to Regional Airports	2013-2020

Table A.13: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0340: Provide Surface Situation to Pilots, Service Providers and Vehicle Operators for Near-Zero Visibility Surface Operations	2025	**L10-02 AO-0203:** Guidance Assistance to Airport Vehicle Driver	2012-2017
		L10-02 AO-0204: Airport Vehicle Driver's Traffic Situational Awareness	2013-2017
		L10-02 AO-0206: Enhanced Guidance Assistance to Airport Vehicle Driver Combined with Routing	2013-2017
		L08-03 AUO-0401: Air Traffic Situational Awareness (ATSAW) on the Airport Surface	2012-2018
		L10-06 AUO-0403: Enhanced Vision for the Pilot in Low Visibility Conditions	2013-2018
		L10-06 AUO-0404: Synthetic Vision for the Pilot in Low Visibility Conditions	2020-2025
		L10-01 AO-0201: Enhanced Ground Controller Situational Awareness in All Weather Conditions	2012-2021
OI-0341: Limited Simultaneous Runway Occupancy	2023	NA	
OI-0347: ADS-B Separation	2010	NA	

Table A.14: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0348: Reduce Separation - High Density Terminal, Less Than 3-miles	2025	NA	
OI-0362: Self-Separation Airspace Operations	2025	**L08-04 CM-0701:** Ad Hoc Delegation of Separation to Flight Deck - In Trail Procedure (ASEP-TIP)	2018-2023
		L08-04 CM-0702: Ad Hoc Delegation of Separation to Flight Deck - Crossing and Passing (C&P)	2020-2025
		L08-04 TS-0105: ASAS Sequencing and Merging as Contribution to Traffic Synchronization in TMA (ASPA-S&M)	2013-2017
		L07-01 TS-0106: Multiple Controlled Times of Over-fly (CTOs) Through Use of Data Link	2018-2023
		L08-04 TS-0107: ASAS Manually Controlled Sequencing and Merging	2013-2020
		L08-05 AUO-0504: Self-Adjustment of Spacing Depending on Wake Vortices	2025-2030
		L08-05 CM-0704: Self Separation in Mixed Mode	2025-2035

Table A.15: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0381: GBAS Precision Approaches	2017	**L10-06 AO-0505:** Improved Low Visibility Runway Operations Using GNSS/GBAS	2013-2018
OI-0383: Improved Runway Safety Situational Awareness for Controllers	2016	**L10-01 AO-0201:** Enhanced Ground Controller Situational Awareness in All Weather Conditions	2012-2021
		L10-02 AO-0205: Automated Assistance to Controller for Surface Movement Planning and Routing	2013-2017
		L06-01 CM-0203: Automated Flight Conformance Monitoring	2008-2016
		L10-01 AO-0102: Automated Alerting of Controller in case of Runway Incursion or Intrusion in Restricted Areas	2010-2017
		L10-01 AO-0103: Improved Runway-Taxiway Layout, Signage and Markings to Prevent Runway Incursions	2012-2019
		L10-01 AO-0104: Airport Safety Nets including Taxiways and Aprons	2013-2018
		L10-01 AUO-0605: Automated Alerting of Runway Incursion to Pilots (and Controllers)	2013-2018

Table A.16: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0384: Improved Runway Safety Situational Awareness for Pilots	2016	**L08-03 AUO-0401:** Air Traffic Situational Awareness (ATSAW) on the Airport Surface	2012-2018
		L10-02 AUO-0603: Enhanced Guidance Assistance to Aircraft on the Airport Surface Combined with Routing	2013-2020
		L10-01 AO-0103: Improved Runway-Taxiway Layout, Signage and Markings to Prevent Runway Incursions	2012-2019
		L10-01 AO-0104: Airport Safety Nets including Taxiways and Aprons	2013-2018
		L10-01 AUO-0605: Automated Alerting of Runway Incursion to Pilots (and Controllers)	2013-2018

Table A.17: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0385: Full Collaborative Decision Making	2020	**L10-03 AO-0501:** Improved Operations in Adverse Conditions through Airport Collaborative Decision Making	2007-2013
		L10-03 AO-0601: Improved Turn-Round Process through Collaborative Decision Making	2010-2016
		L10-02 AUO-0602: Guidance Assistance to Aircraft on the Airport Surface	2013-2020
		L10-02 AUO-0603: Enhanced Guidance Assistance to Aircraft on the Airport Surface Combined with Routing	2013-2020
		L10-04 DCB-0303: Improved Operations at Airport in Adverse Conditions using ATFCM Techniques	2010-2016
		L10-03 DCB-0304: Airport CDM extended to Regional Airports	2013-2020

Table A.18: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0386: Expanded Radar-like Services to Secondary Airports	2016	**L07-02 TS-0303:** Arrival Management into Multiple Airports	2015-2020
		L02-09 SDM-0201: Remotely Provided Aerodrome Control Service	2020-2025
		L10-03 DCB-0304: Airport CDM extended to Regional Airports	2013-2020
OI-0387: Dynamic, Pairwise Wake Turbulence Separation	2025	**L10-05 AO-0304:** Dynamic Adjustment of Separations Based on Real-Time Detection of Wake Vortex	2015-2019
		L08-05 AUO-0504: Self-Adjustment of Spacing Depending on Wake Vortices	2025-2030
OI-0388: Low Visibility/Ceiling Takeoff Operations	2018	**L10-06 AUO-0403:** Dynamic Enhanced Vision for the Pilot in Low Visibility Conditions	2013-2018
		L10-06 AUO-0404: Synthetic Vision for the Pilot in Low Visibility Conditions	2020-2025
OI-0389: Low Visibility/Ceiling Landing Operations	2018	**L10-06 AO-0503:** Reduced ILS Sensitive and Critical Areas	2008-2015
		L10-06 AO-0504: Improved Low Visibility Runway Operations	2008-2013
		L10-06 AO-0505: Improved Low Visibility Runway Operations Using GNSS/GBAS	2013-2018
OI-0390: Low Visibility/Ceiling Departure Operations	2018	NA	

Table A.19: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0400: Wake Turbulence Mitigation for Wind-Based Wake Procedures	2016	**L10-05 AO-0303:** Fixed Reduced Separations Based on Wake Vortex Prediction	2013-2020
		L10-05 AO-0304: Dynamic Adjustment of Separations Based on Real-Time Detection of Wake Vortex	2015-2019
		L10-05 AO-0301: Crosswind Reduced Separations for Departures and Arrivals	2015-2019
OI-0401: Wake Turbulence Mitigation for Arrivals: CSPRs	2018	**L10-05 AO-0303:** Fixed Reduced Separations Based on Wake Vortex Prediction	2013-2020
		L10-05 AO-0304: Dynamic Adjustment of Separations Based on Real-Time Detection of Wake Vortex	2015-2019
		L10-05 AO-0301: Crosswind Reduced Separations for Departures and Arrivals	2015-2019
		L10-05 AO-0302: Basic Time Based Separation for Final Approach	2012-2015
OI-0402: Single Runway Departure Wake Mitigation	2021	**L10-05 AO-0301:** Crosswind Reduced Separations for Departures and Arrivals	2015-2019
OI-0403: Single Runway Arrival Wake Mitigation	2021	**L10-05 AO-0301:** Crosswind Reduced Separations for Departures and Arrivals	2015-2019

Table A.20: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-0408: Provide Full Flight Plan Constraint Evaluation with Feedback	2014	**L10-01 DCB-0301:** Improved Consistency between Airport Slots, Flight Plans and ATFM Slots	2012-2015
		L05-02 CM-0101: Automated Support for Traffic Load (Density) Management	2007-2010
		L05-02 CM-0103: Automated Support for Traffic Complexity Assessment	2013-2019
		L05-02 CM-0104: Automated Controller Support for Trajectory Management	2016-2022
		L06-03 CM-0405: Automated Assistance to ATC Planning for Preventing Conflicts in Terminal Areas Operations	2015-2020
OI-0409: Remotely Staffed Tower Services	2018	**L02-09 SDM-0201:** Remotely Provided Aerodrome Control Service	2020-2025
OI-0410: Automated Virtual Towers	2023	NA	
OI-5000: Airport Preservation	2015	NA	
OI-5002: Improved Strategic Management of Existing Infrastructure (Airside)	2020	NA	

Table A.21: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-5004: New Airside Airport Infrastructure	2025	NA	
OI-5006: Coordinated Ramp Operations Management	2014	**L10-02 AO-0204:** Airport Vehicle Driver's Traffic Situational Awareness	2013-2017
		L10-02 AO-0206: Enhanced Guidance Assistance to Airport Vehicle Driver Combined with Routing	2013-2017
		L10-02 AO-0203: Guidance Assistance to Airport Vehicle Driver	2012-2017
		L08-03 AUO-0401: Air Traffic Situational Awareness (ATSAW) on the Airport Surface	2012-2018
		L10-02 AUO-0602: Guidance Assistance to Aircraft on the Airport Surface	2013-2020
		L10-02 AUO-0603: Enhanced Guidance Assistance to Aircraft on the Airport Surface Combined with Routing	2013-2020
OI-5008: Advanced Weather Capability for Airside Facilities	2022	**L10-03 AO-0501:** Improved Operations in Adverse Conditions through Airport Collaborative Decision Making	2007-2013
OI-5010: Advanced Winter Weather Operations - Level 1	2020	**L10-03 AO-0603:** Improved De-icing Operation through Collaborative Decision Making	2010-2016
OI-5110: Advanced Winter Weather Operations - Level 2	2025	NA	

Table A.22: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-7002: Expanded Traffic Advisory Services using Digital Traffic Data	2010	**L08-03 AUO-0401:** Air Traffic Situational Awareness (ATSAW) on the Airport Surface	2012-2018
		L08-03 AUO-0402: Air Traffic Situational Awareness (ATSAW) during Flight Operations (AIRB)	2012-2019
		L10-02 AUO-0603: Enhanced Guidance Assistance to Aircraft on the Airport Surface Combined with Routing	2013-2020
		L10-06 AUO-0404: Synthetic Vision for the PIlot in Low Visibility Conditions	2020-2025
OI-7004: Point-in-Space Metering	2014	**L08-01 CM-0501:** 4D Contract for Equipped Aircraft with Extended Clearance PTC-4D	2025-2030
		L08-02 CM-0601: Precision Trajectory Clearances (PTC-2D) Based on Pre-defined 2D Routes	2013-2020
		L08-02 CM-0602: Precision Trajectory Clearances (PTC-3D) Based on Pre-defined 3D Routes	2017-2022
		L08-02 CM-0603: Precision Trajectory Clearances (PTC-2D) Based on User Pre-defined Trajectories	2017-2022
		L08-02 CM-0604: Precision Trajectory Clearances (PTC-3D) Based on User Pre-defined Trajectories	2020-2025

Table A.23: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-7004: Point-in-Space Metering (Continued)	2014	**L02-08 AOM-0704:** Tailored Arrival	2015-2018
		L07-01 TS-0103: Controlled Time of Arrival (CTA) Through Use of Datalink	2016-2019
		L07-01 TS-0106: Multiple Controlled Times of Over-fly (CTOs) Through Use of Data Link	2018-2023
		L02-07 AOM-0603: Enhanced Terminal Airspace for RNP-based Operations	2015-2020
OI-7005: Enhanced Departure Flow Operations	2018	**L10-01 AO-0201:** Enhanced Ground Controller Situational Awareness in All Weather Conditions	2012-2021
		L10-03 AO-0602: Collaborative Pre-Departure Sequencing	2010-2016
		L07-02 TS-0202: Departure Management Synchronized with Pre-Departure Sequencing	2013-2020
		L07-02 TS-0203: Integration of Surface Management Constraint into Departure Management	2014-2018
		L07-03 TS-0301: Integrated Arrival Departure Management for Full Traffic Optimization, including within the TMA Airspace	2020-2025
		L07-02 TS-0306: Optimized Departure Management in the Queue Management Process	2015-2019

Table A.24: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-7005: Enhanced Departure Flow Operations (Continued)	2018	**L10-01 AO-0201:** Enhanced Ground Controller Situational Awareness in All Weather Conditions	2012-2021
		L10-05 AO-0304: Dynamic Adjustment of Separations Based on Real-Time Detection of Wake Vortex	2015-2019
		L10-04 AUO-0701: Use of Runway Occupancy Time (ROT) Reduction Techniques	2007-2013
OI-7008: Delegated Responsibility for In-Trail Separation	2014	**L08-05 AUO-0504:** Self-Adjustment of Spacing Depending on Wake Vortices	2025-2030
		L08-04 CM-0701: Ad Hoc Delegation of Separation to Flight Deck - In Trail Procedure (ASEP-TIP)	2018-2023
		L08-04 CM-0702: Ad Hoc Delegation of Separation to Flight Deck - Crossing and Passing (C&P)	2020-2025
		L08-05 CM-0704: Self Separation in Mixed Mode	2025-2035
		L08-04 TS-0105: ASAS Sequencing and Merging as Contribution to Traffic Synchronization in TMA (ASPA-S&M)	2013-2017

Table A.25: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-7010: Wake Re-categorization	2016	**L10-05 AO-0301:** Crosswind Reduced Separations for Departures and Arrivals	2015-2019
		L10-05 AO-0303: Fixed Reduced Separations Based on Wake Vortex Prediction	2013-2020
		L10-05 AO-0304: Dynamic Adjustment of Separations Based on Real-Time Detection of Wake Vortex	2015-2019
		L08-05 AUO-0504: Self-Adjustment of Spacing Depending on Wake Vortices	2025-2030
OI-7011: Time-Based Metering in the Terminal Environment	2016	**L02-07 AOM-0603:** Enhanced Terminal Airspace for RNP-based Operations	2015-2020
OI-7012: Provide Full Surface Situation Information	2019	**L10-01 AO-0202:** Detection of FOD (Foreign Object Debris on the) Airport Surface	2010-2015
		L10-01 AO-0201: Enhanced Ground Controller Situational Awareness in All Weather Conditions	2012-2021
		L10-02 AO-0203: Guidance Assistance to Airport Vehicle Driver	2012-2017
		L10-02 AO-0204: Airport Vehicle Driver's Traffic Situational Awareness	2013-2017
		L10-02 AO-0206: Enhanced Guidance Assistance to Airport Vehicle Driver Combined with Routing	2013-2017

Table A.26: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
OI-7012: Provide Full Surface Situation Information (Continued)	2019	**L08-03 AUO-0401:** Air Traffic Situational Awareness (ATSAW) on the Airport Surface	2012-2018
		L10-02 AUO-0603: Enhanced Guidance Assistance to Aircraft on the Airport Surface Combined with Routing	2013-2020
		L10-01 AO-0102: Automated Alerting of Controller in case of Runway Incursion or Intrusion in Restricted Areas	2010-2017
		L10-01 AO-0104: Airport Safety Nets including Taxiways and Aprons	2013-2018
		L10-01 AUO-0605: Automated Alerting of Runway Incursion to Pilots (and Controllers)	2013-2018
		L10-02 AUO-0602: Guidance Assistance to Aircraft on the Airport Surface	2013-2020
OI-7013: Automated Support for Conflict Resolution	2020	**L10-01 AO-0102:** Automated Alerting of Controller in case of Runway Incursion or Intrusion in Restricted Areas	2010-2017
		L10-01 AO-0104: Airport Safety Nets including Taxiways and Aprons	2013-2018
		L09-01 CM-0801: Ground Based Safety Nets (TMA, En Route)	2008-2013
		L09-01 CM-0802: ACAS Resolution Advisory Downlink	2017-2022
		L06-01 CM-0203: Automated Flight Conformance Monitoring	2008-2016

Table A.27: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	**NextGen Conflict**	**SESAR Operational Improvements and Steps**	**Deployment Start-End**
OI-7013: Automated Support for Conflict Resolution (Continued)	2020	**L05-02 CM-0104:** Automated Controller Support for Trajectory Management	2016-2022
		L06-03 CM-0406: Automated Assistance to ATC for Detecting Conflicts in Terminal Areas Operations	2015-2020
		L10-02 AO-0205: Automated Assistance to Controller for Surface Movement Planning and Routing	2013-2017
NA		**L10-01 AO-0101:** Reduced Risk of Runway Incursions through Improved Procedures and Best Practices on the Ground	2007-2013
NA		**L02-08 AOM-0703:** Continuous Climb Departure	2007-2015
NA		**L02-08 AOM-0705:** Advanced Continuous Climb Departure	2013-2017
NA		**L10-07 AUO-0501:** Visual Contact Approaches when Appropriate Visual Conditions Prevail	2009-2015
NA		**L10-04 AUO-0702:** Brake to Vacate (BTV) Procedure	2013-2020
NA		**L10-04 AUO-0703:** Automated Brake to Vacate (BTV) using Datalink	2013-2018
NA		**L09-01 CM-0803:** Enhanced TCAS Compliant with Change 7.1	2009-2013
NA		**L09-01 CM-0804:** ACAS Adapted to New Separation Modes	2020-2025

Table A.28: Comparison of selected NextGen and SESAR improvements (continued)

NextGen Operational Improvements	NextGen IOC	SESAR Operational Improvements and Steps	Deployment Start-End
NA		**L09-01 CM-0805:** Short Term Conflict Alert Adapted to New Separation Modes	2020-2025
NA		**L09-01 CM-0806:** Improved Compatibility between Ground and Airborne Safety Nets	2020-2030
NA		**L09-01 CM-0807:** Enhanced Ground-based Safety Nets using Wide Information Sharing	2017-2020

APPENDIX B

OPERATIONAL IMPROVEMENTS' MAPPINGS

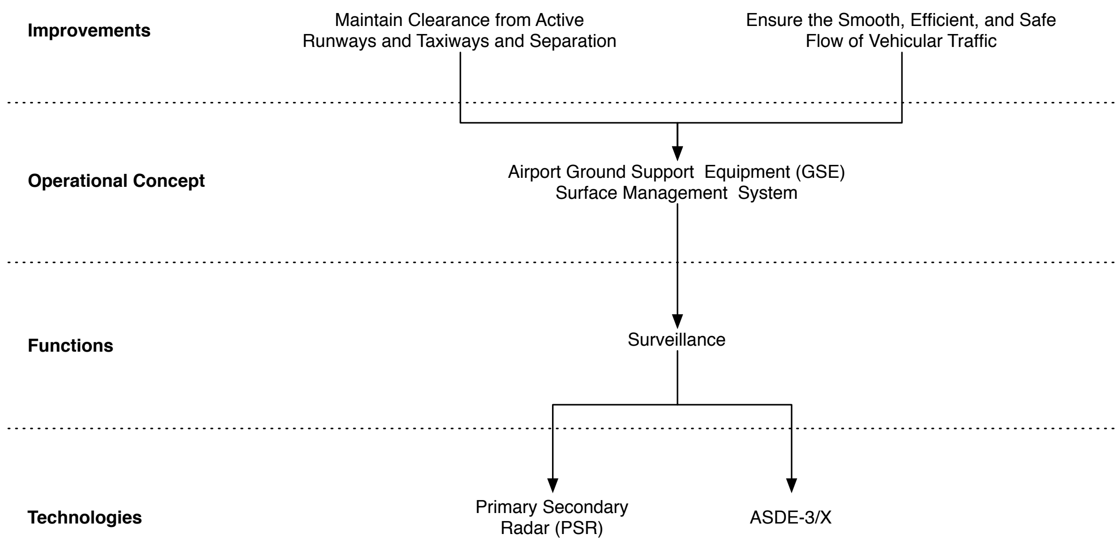


Figure B.1: Airport Ground Support Equipment (GSE) Surface Management System

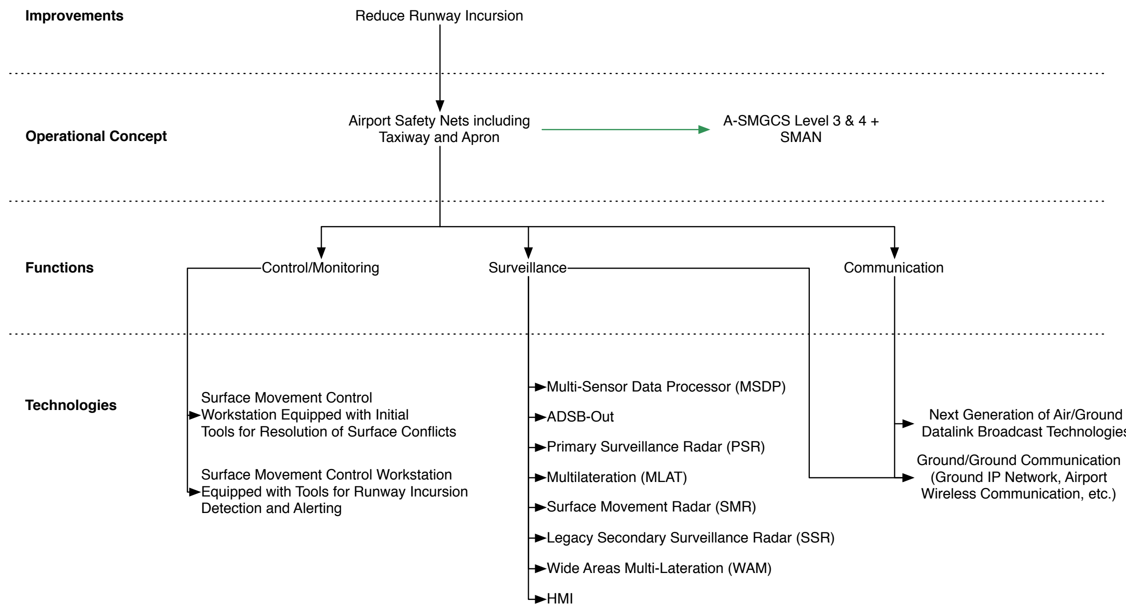


Figure B.2: Airport Safety Nets including Taxiway and Apron

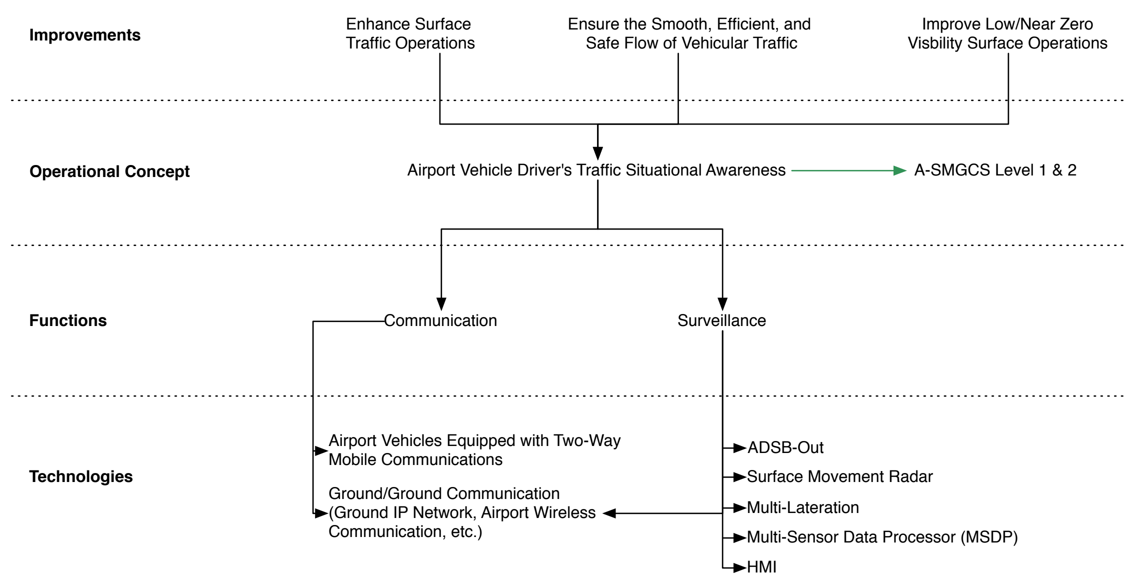


Figure B.3: Airport Vehicle Drivers Traffic Situational Awareness

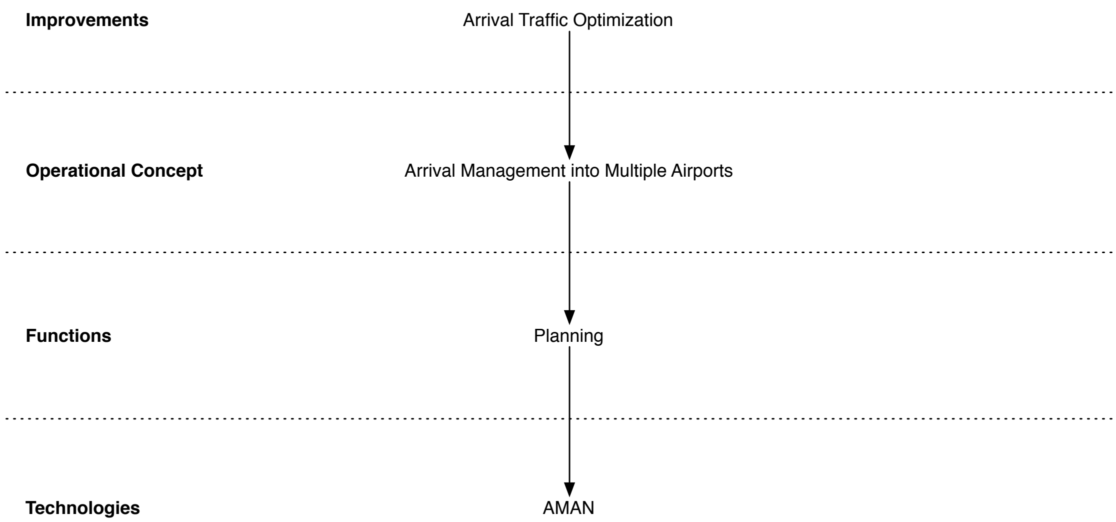


Figure B.4: Arrival Management into Multiple Airports

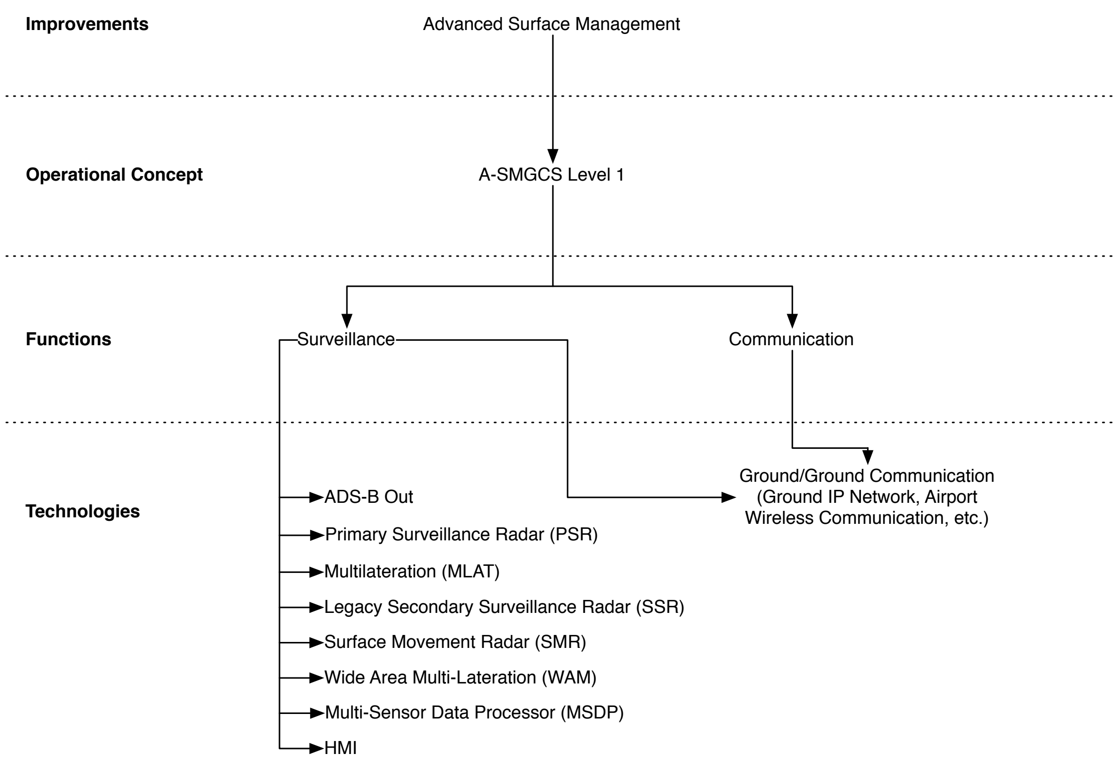


Figure B.5: A-SMGCS Level 1

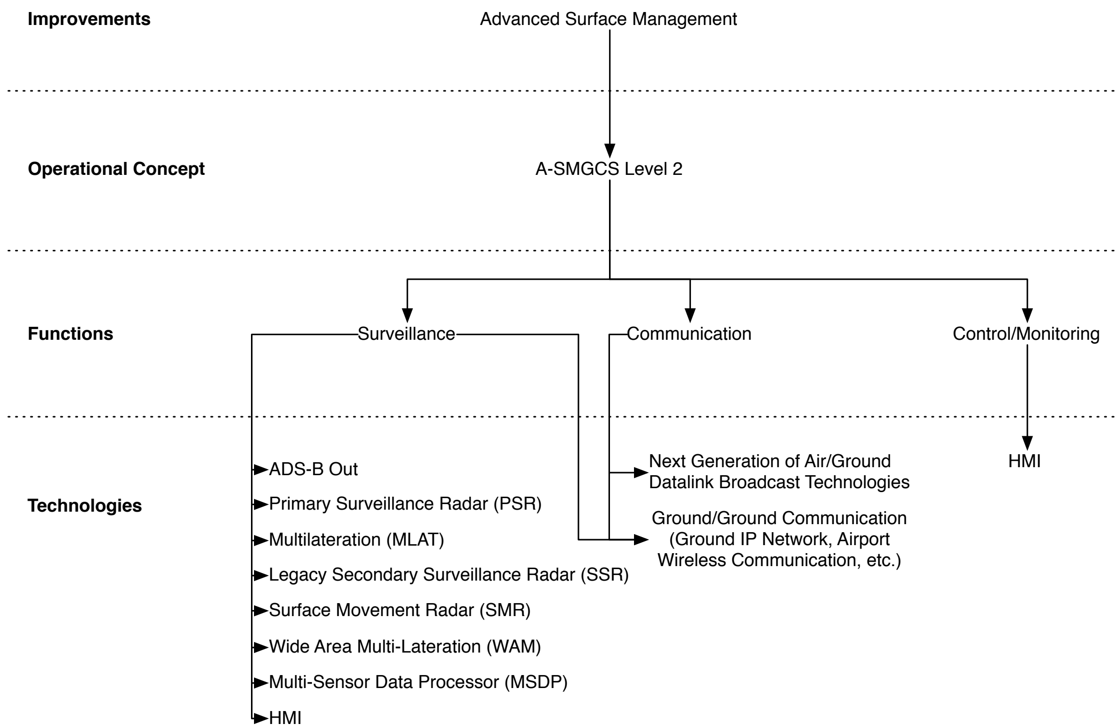


Figure B.6: A-SMGCS Level 2

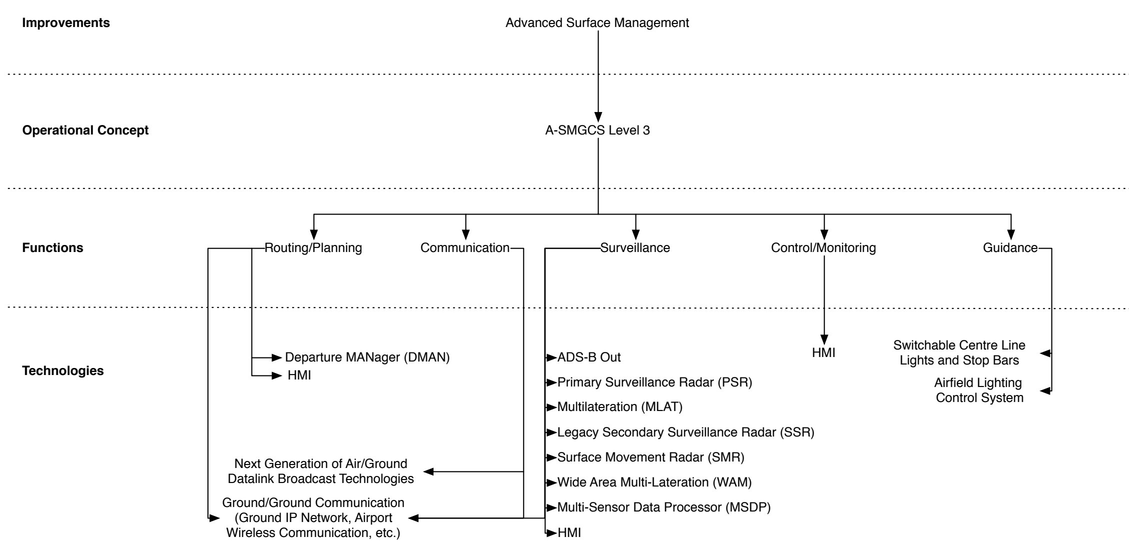


Figure B.7: A-SMGCS Level 3

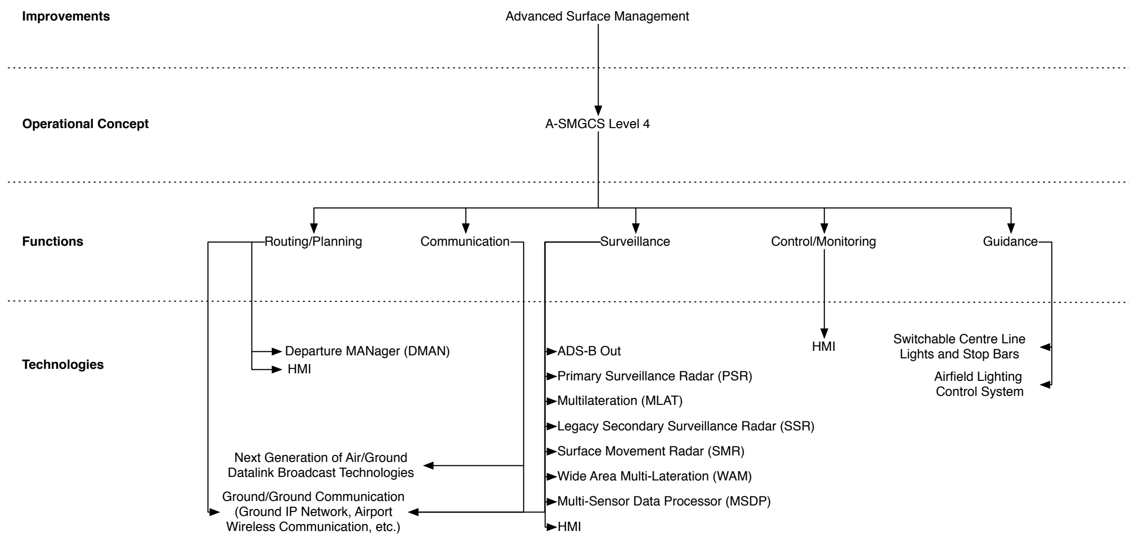


Figure B.8: A-SMGCS Level 4

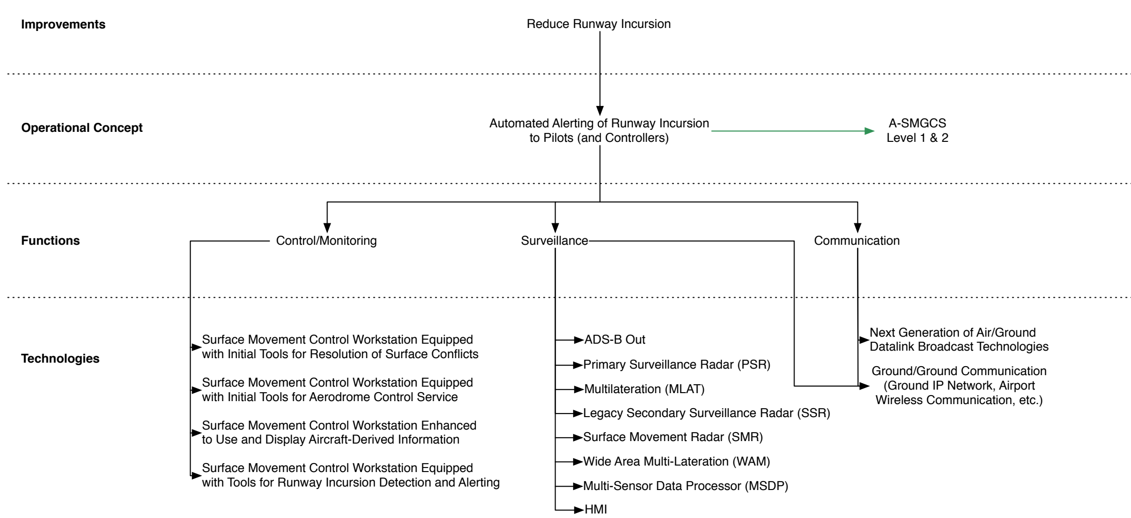


Figure B.9: Automated Alerting of Runway Incursion to Pilots (and Controllers)

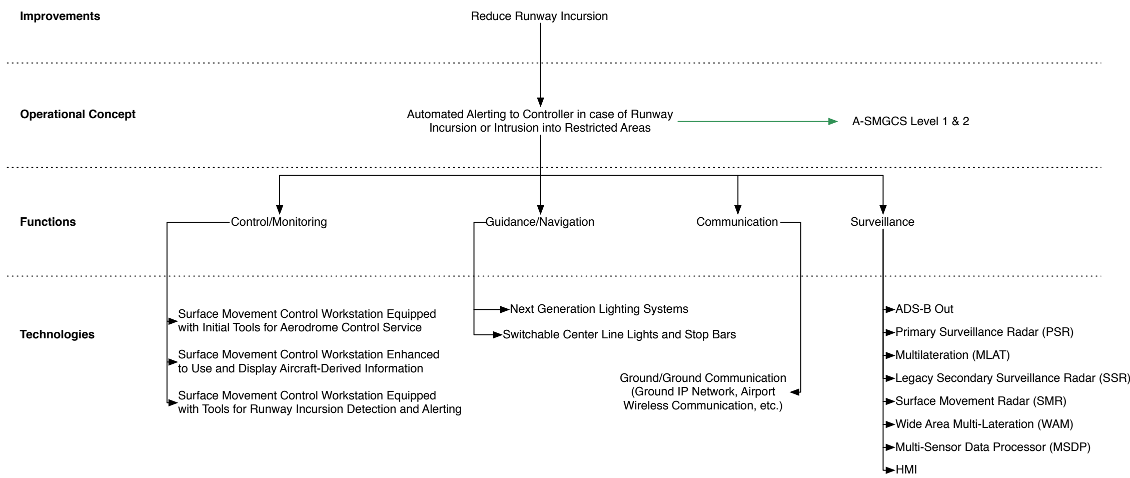


Figure B.10: Automated Alerting to Controller in Case of Runway Incursion or Intrusion into Restricted Areas

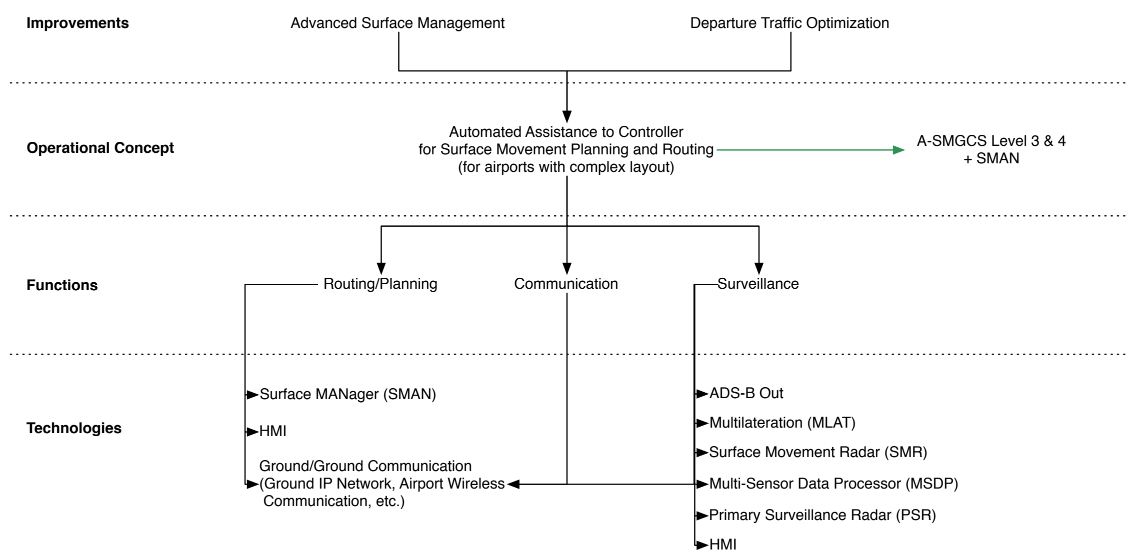


Figure B.11: Automated Assistance to Controller for Surface Movement Planning and Routing (for airports with complex layout)

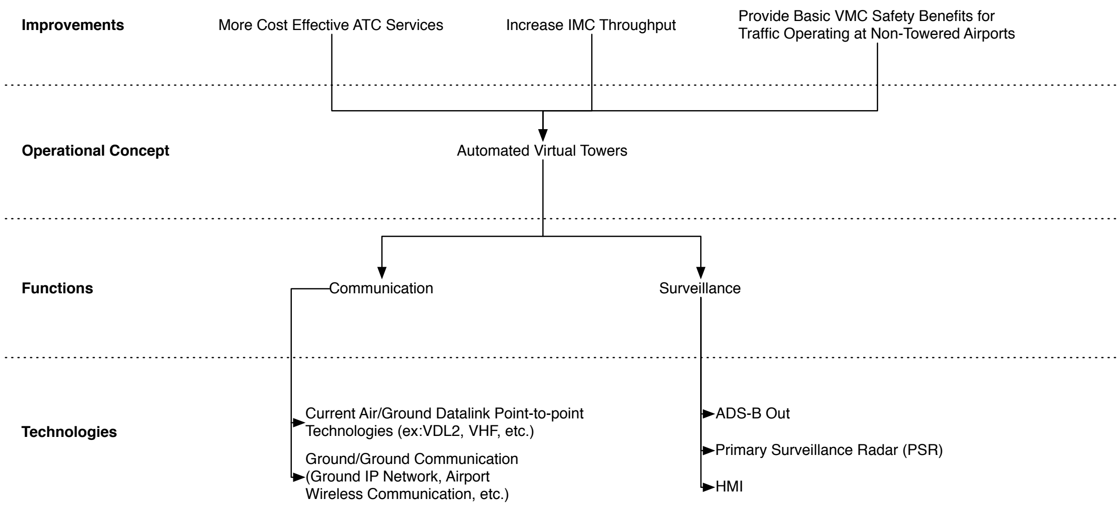


Figure B.12: AutomatedVirtualTowers

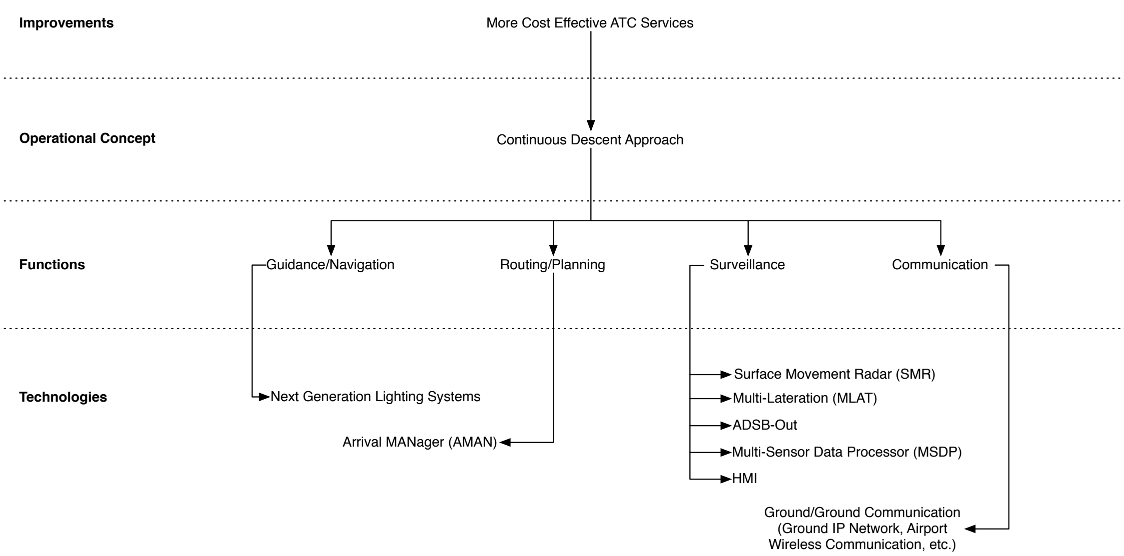


Figure B.13: Continuous Descent Approach

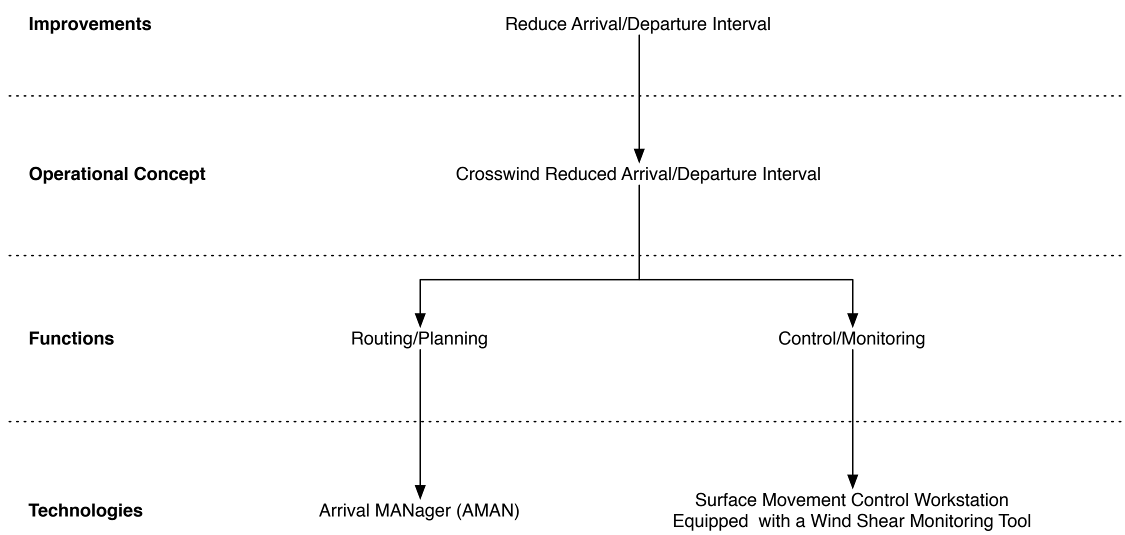


Figure B.14: Crosswind Reduced Arrival Departure Interval

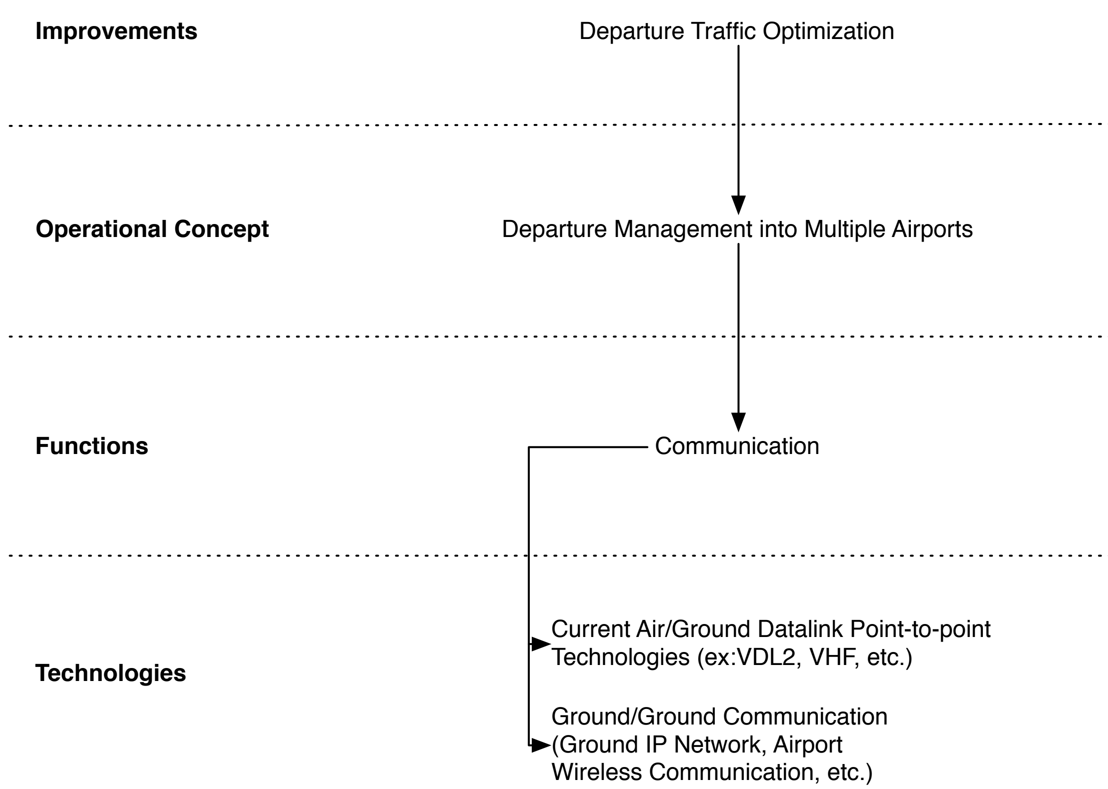


Figure B.15: Departure Management into Multiple Airports

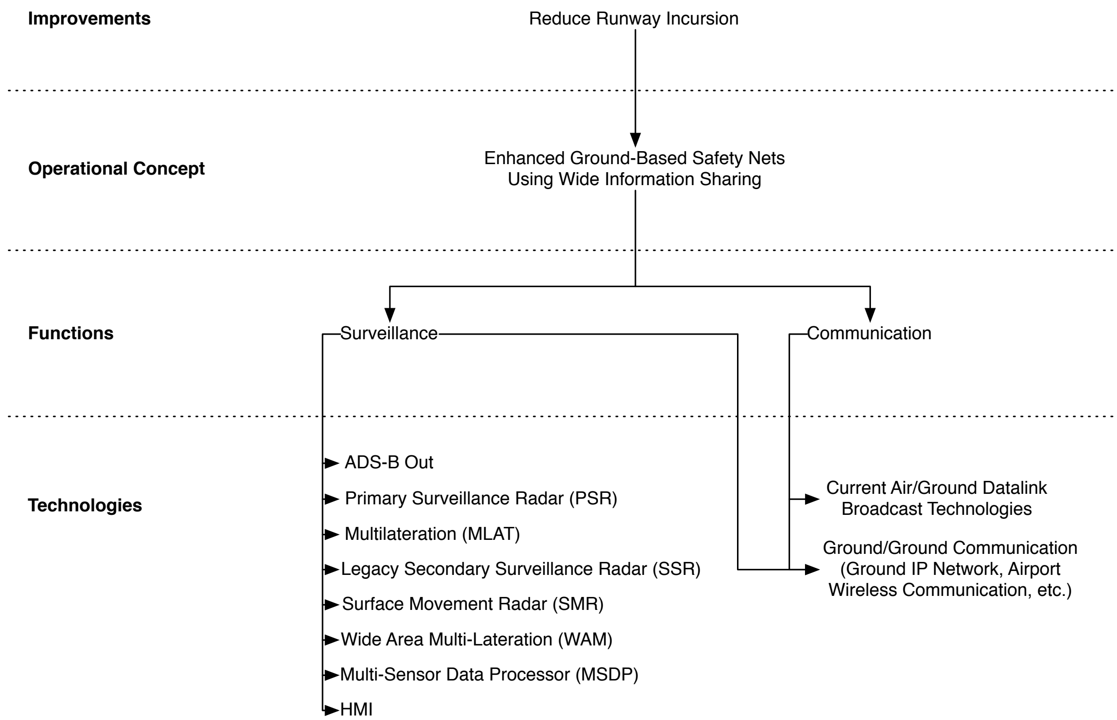


Figure B.16: Enhanced Ground Based Safety Nets Using Wide Information Sharing

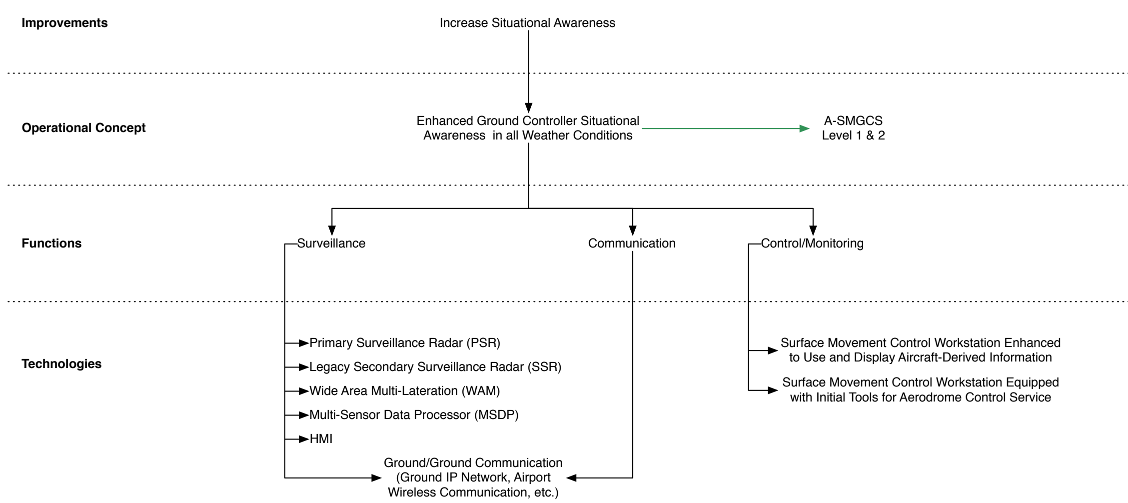


Figure B.17: Enhanced Ground Controller Situational Awareness in all Weather Conditions

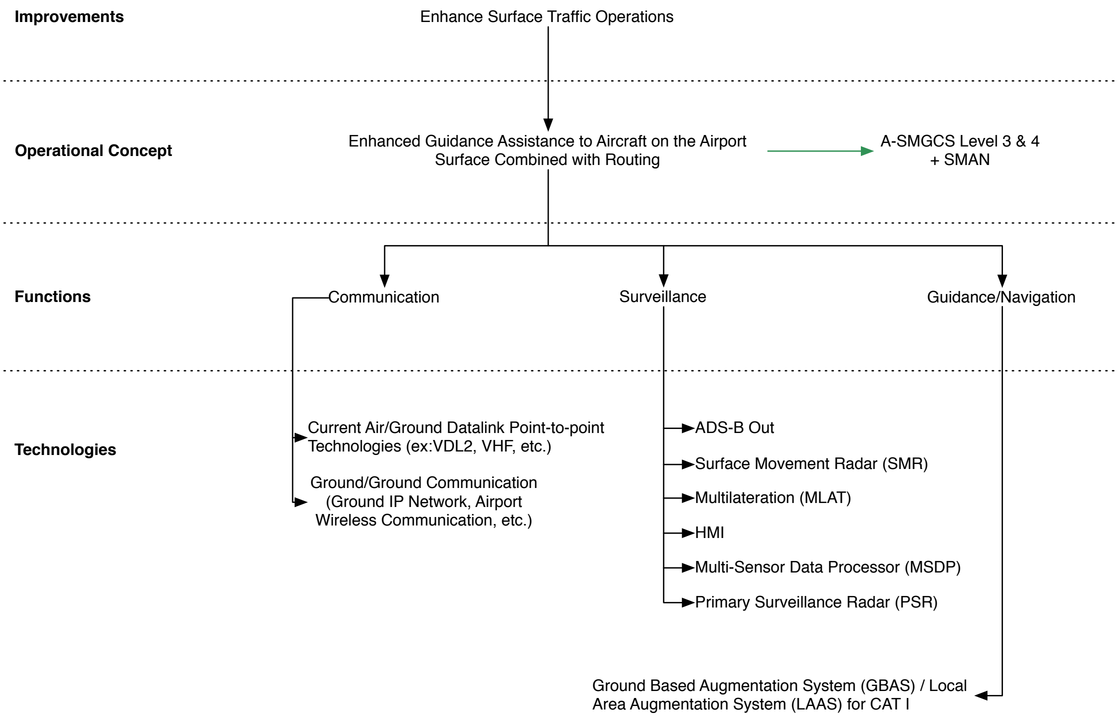


Figure B.18: Enhanced Guidance Assistance to Aircraft on the Airport Surface Combined with Routing

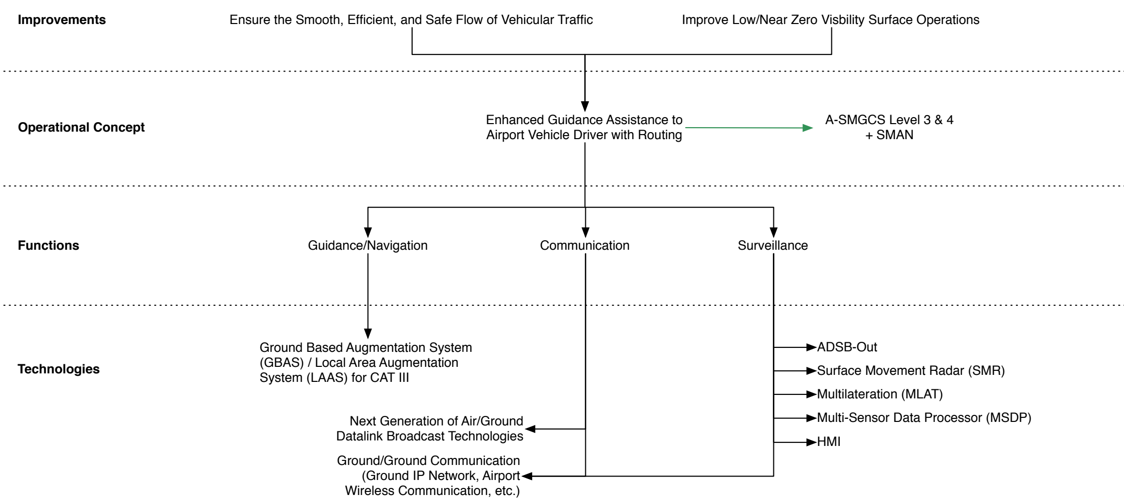


Figure B.19: Enhanced Guidance Assistance to Airport Vehicle Driver with Routing

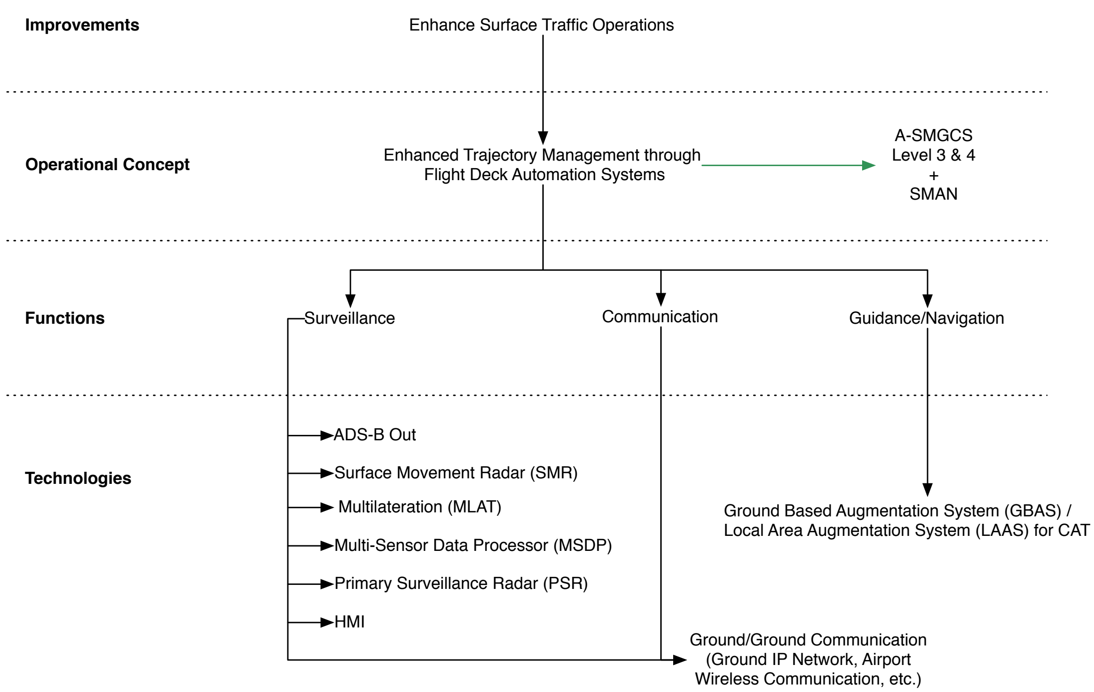


Figure B.20: Enhanced Trajectory Management through Flight Deck Automation Systems

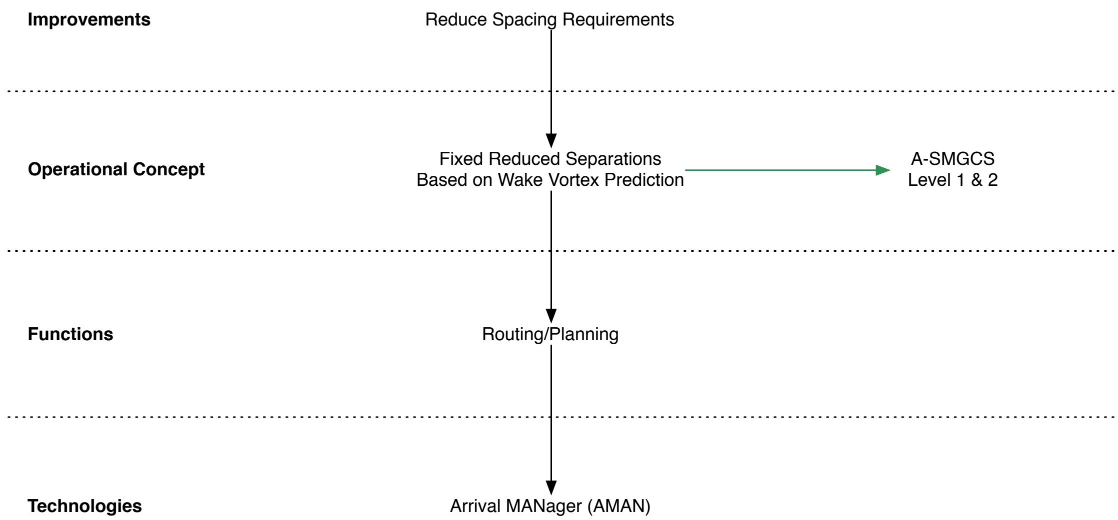


Figure B.21: Fixed Reduced Separations Based on Wake Vortex Prediction

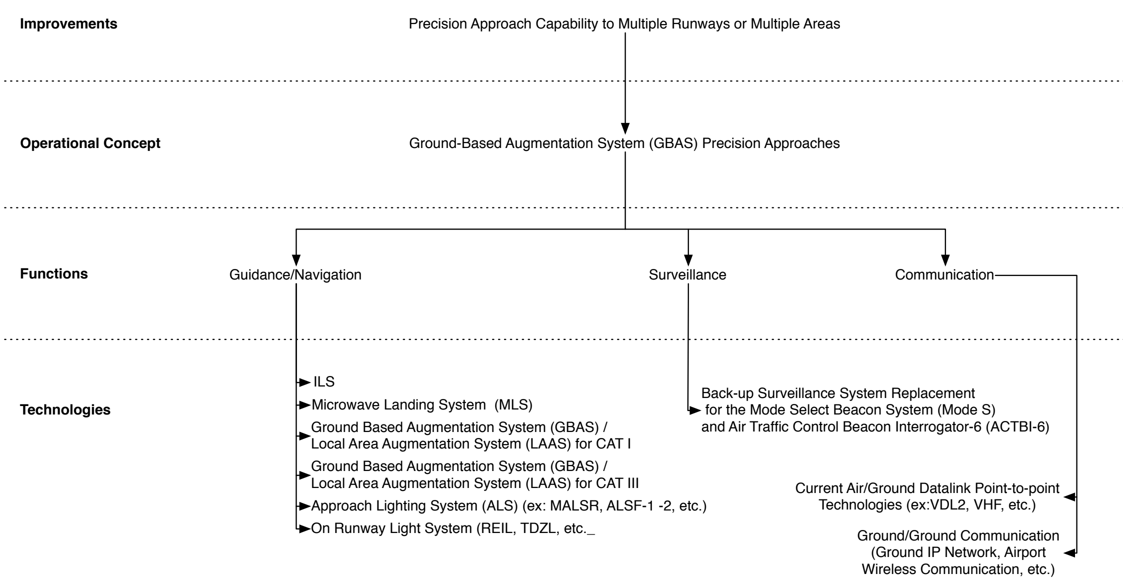


Figure B.22: Ground Based Augmentation System (GBAS) Precision Approaches

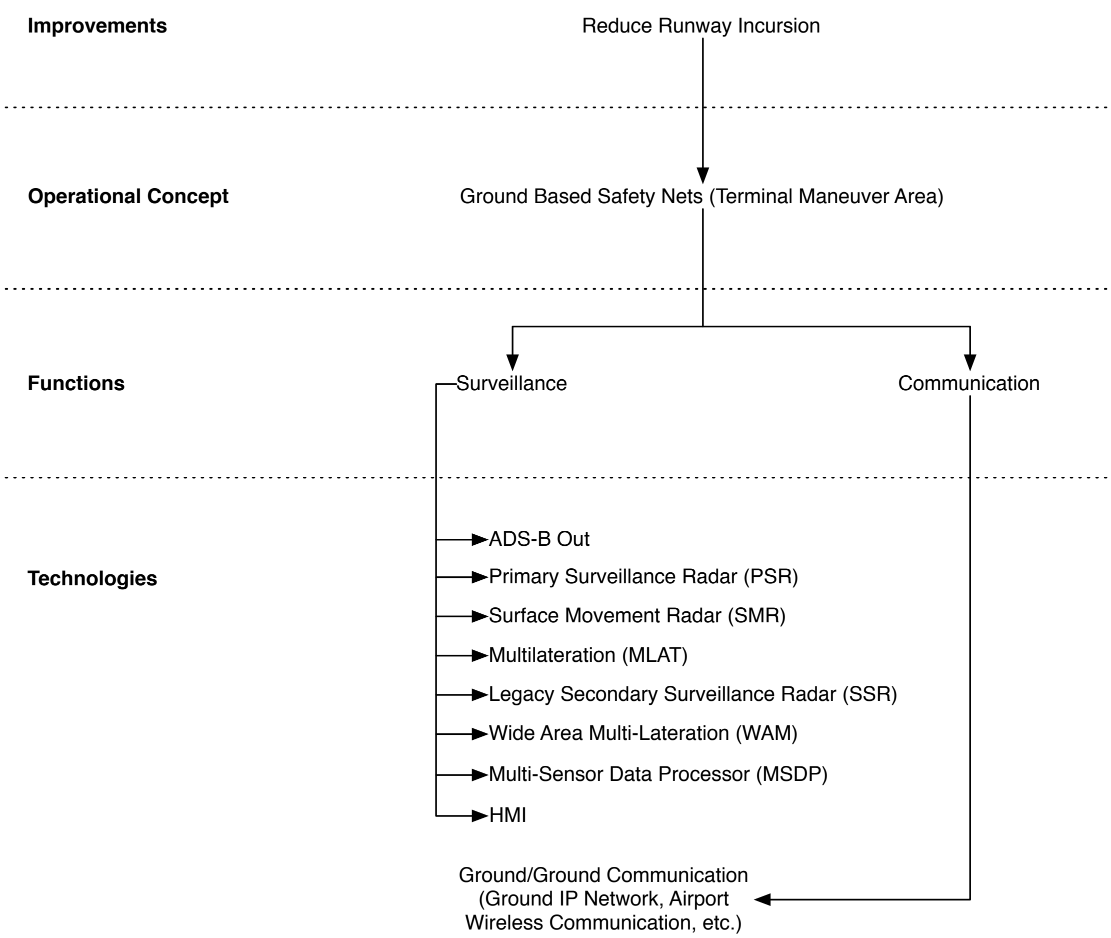


Figure B.23: Ground Based Safety Nets (Terminal Maneuver Area and En Route)

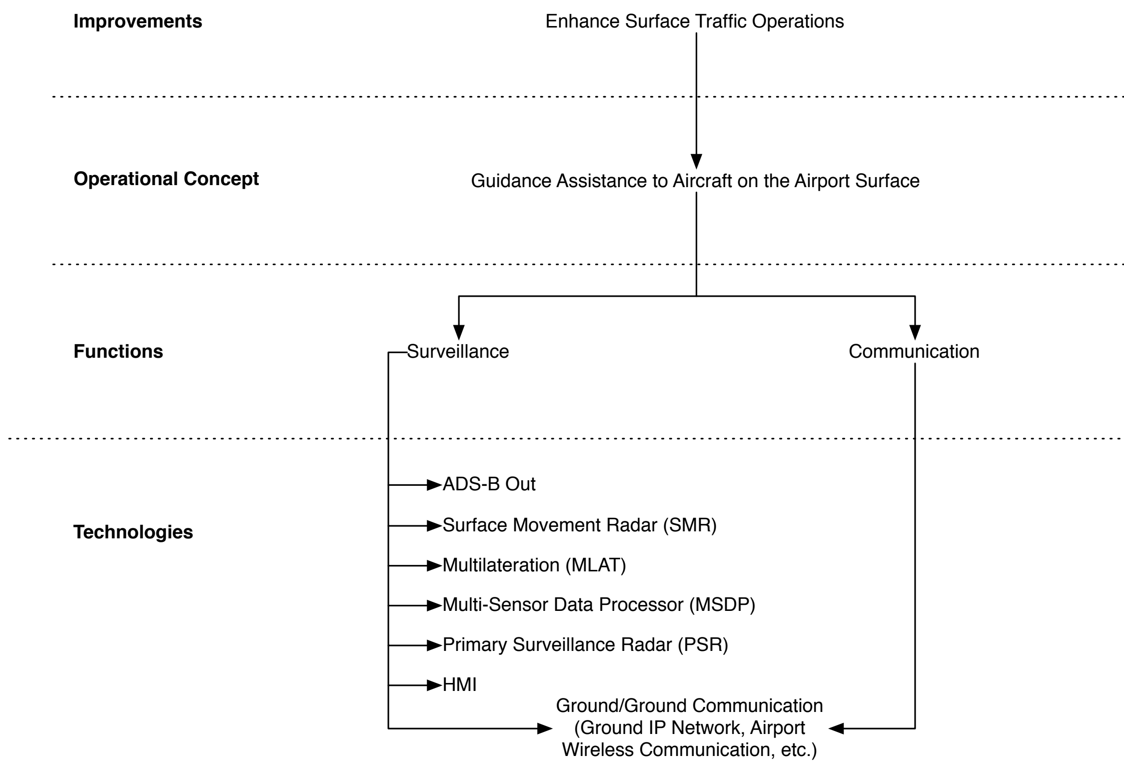


Figure B.24: Guidance Assistance to Aircraft on the Airport Surface

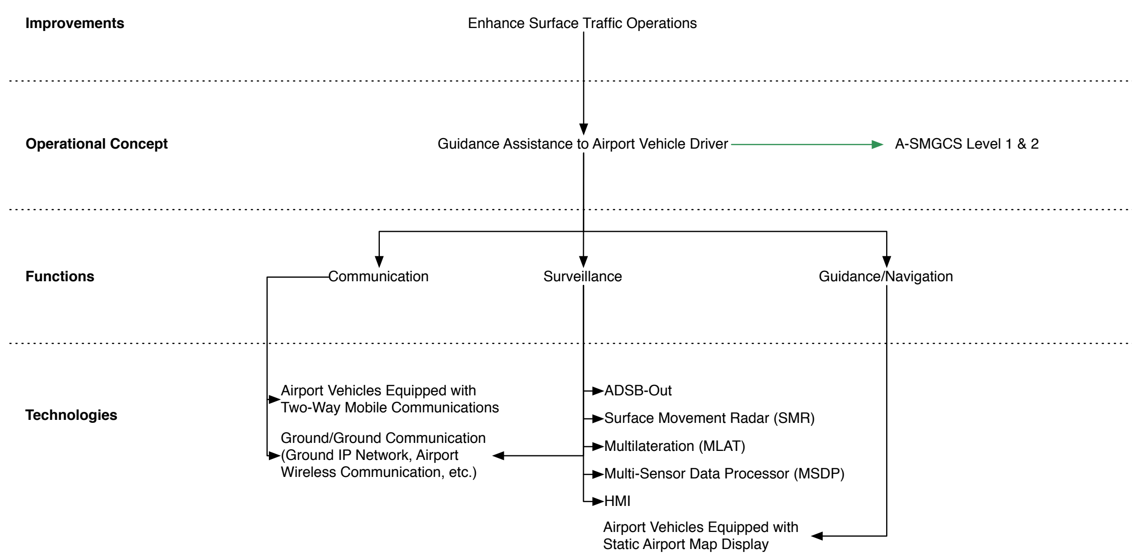


Figure B.25: Guidance Assistance to Airport Vehicle Driver

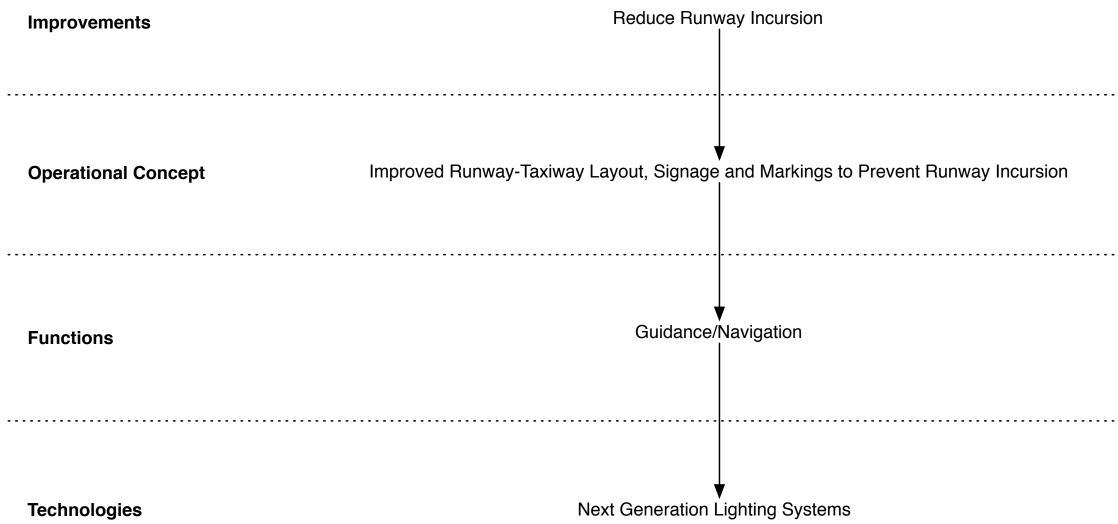


Figure B.26: Improved Runway Taxiway Layout Signage and Markings to Prevent Runway Incursion

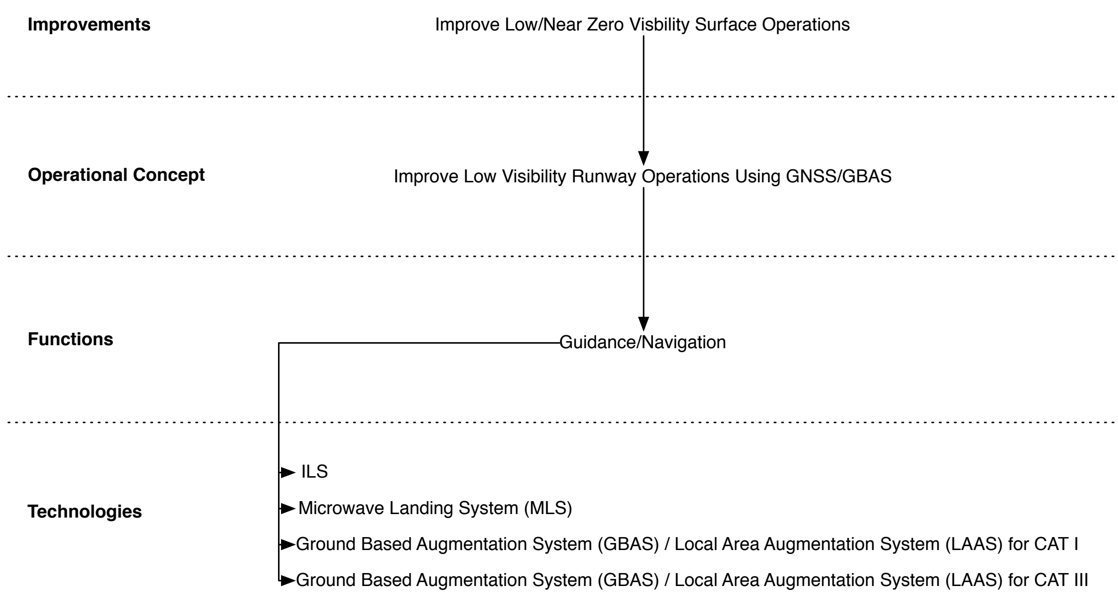


Figure B.27: Improved Low Visibility Runway Operations Using GNSS/GBAS

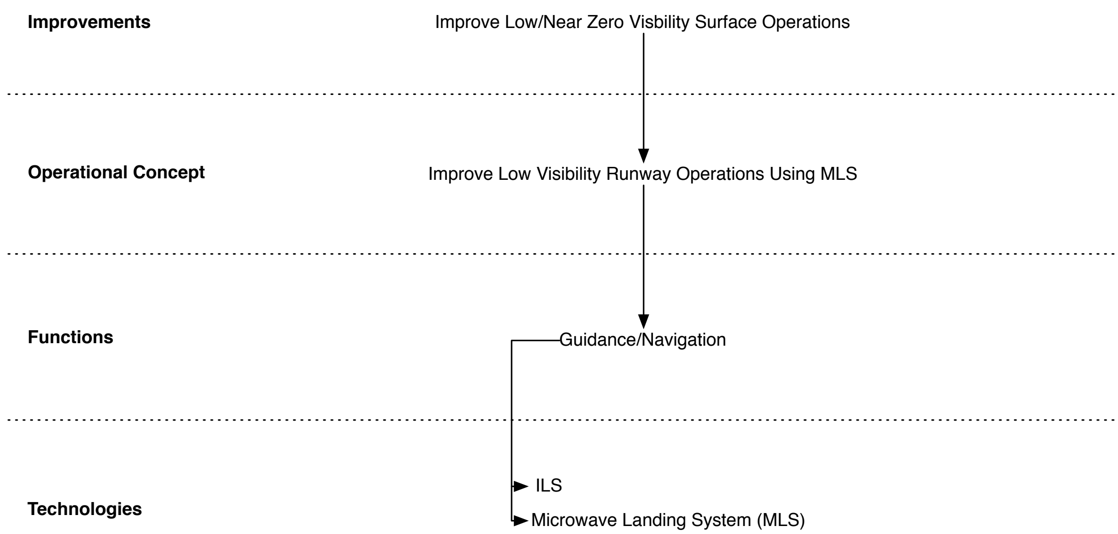


Figure B.28: Improve Low Visibility Runway Operations Using MLS

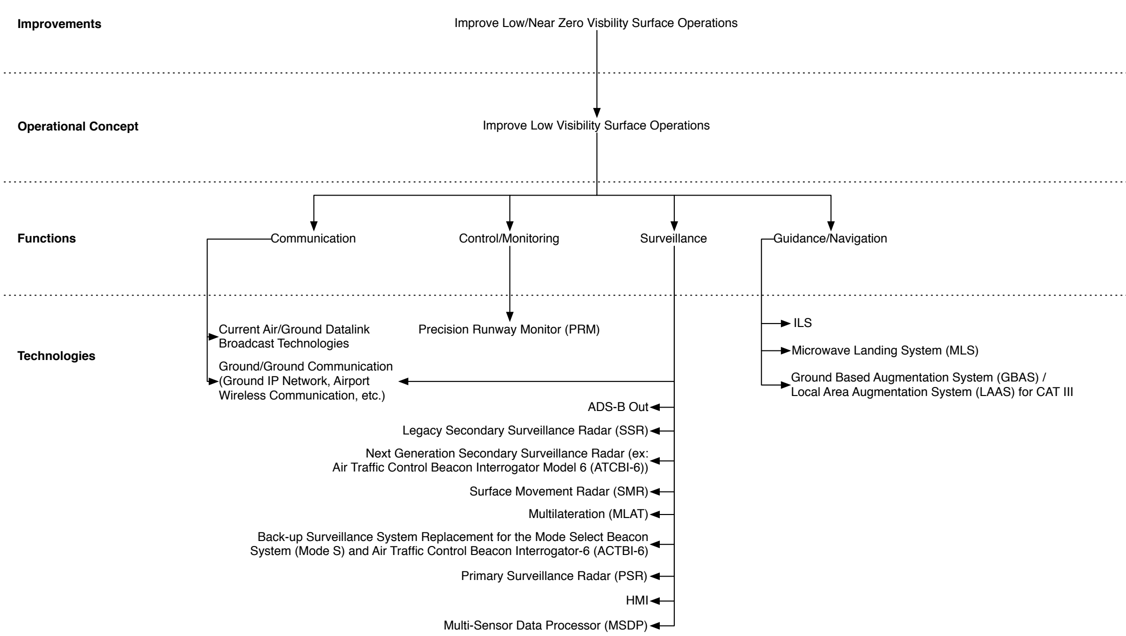


Figure B.29: Improve Low Visibility Surface Operations

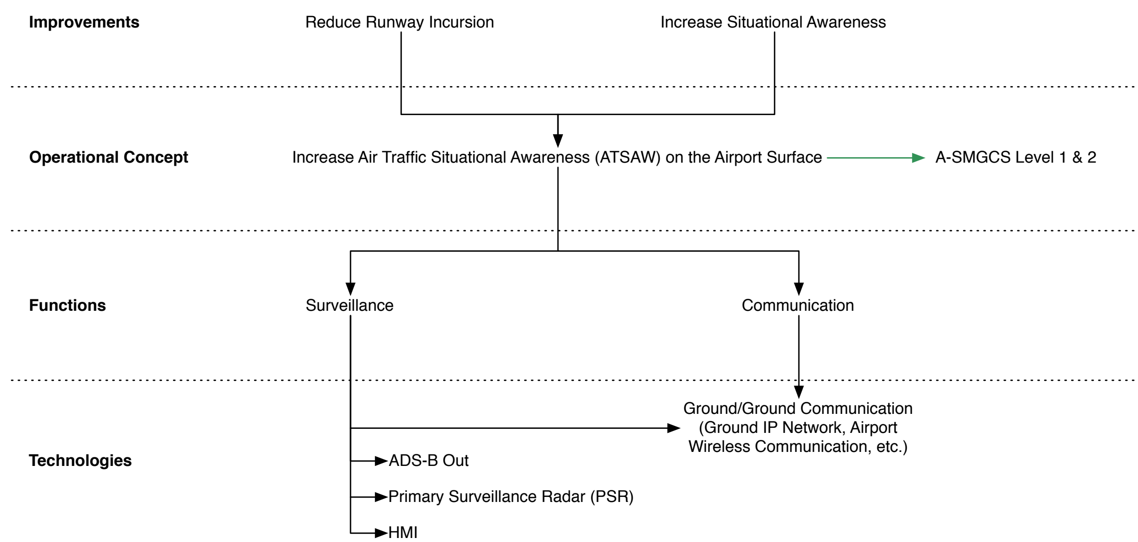


Figure B.30: Increase Air Traffic Situational Awareness (ATSAW) on the Airport Surface

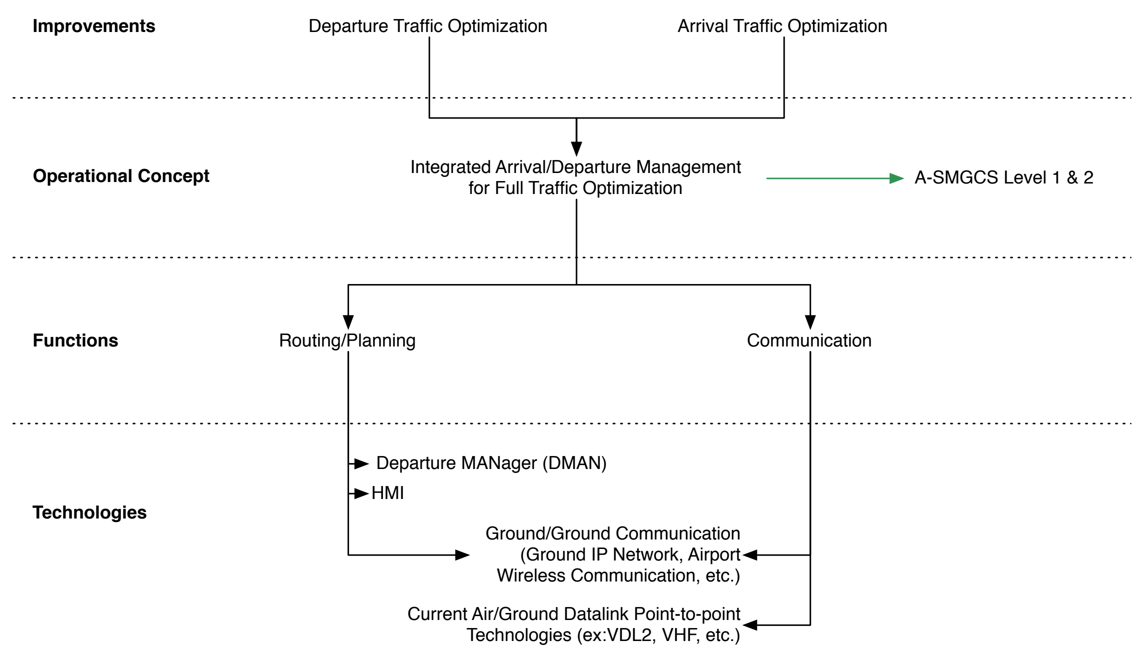


Figure B.31: Integrated Arrival Departure Management for Full Traffic Optimization

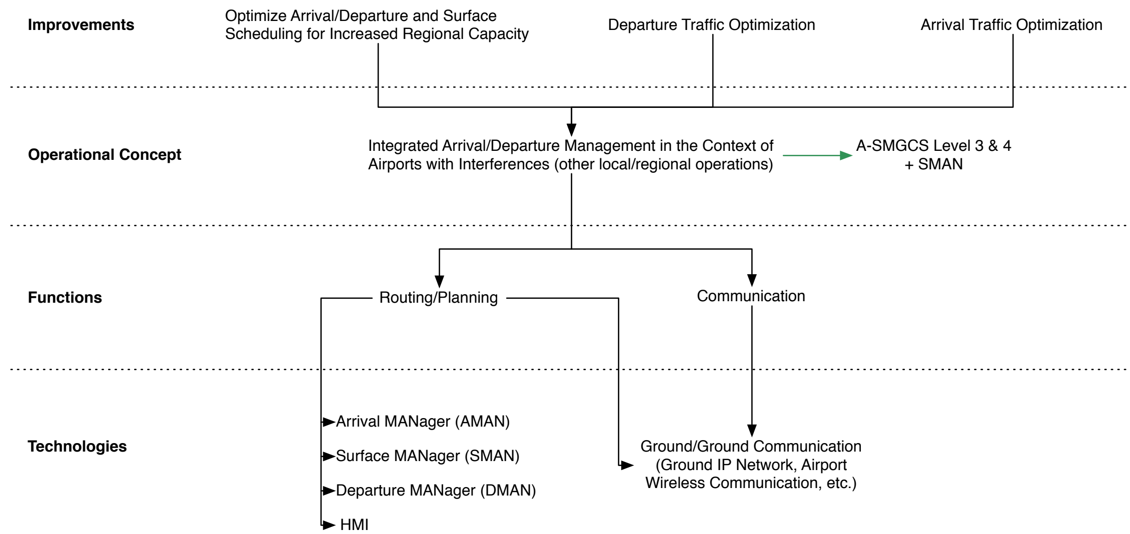


Figure B.32: Integrated Arrival Departure Management in the Context of Airports with Interferences (other local regional operations)

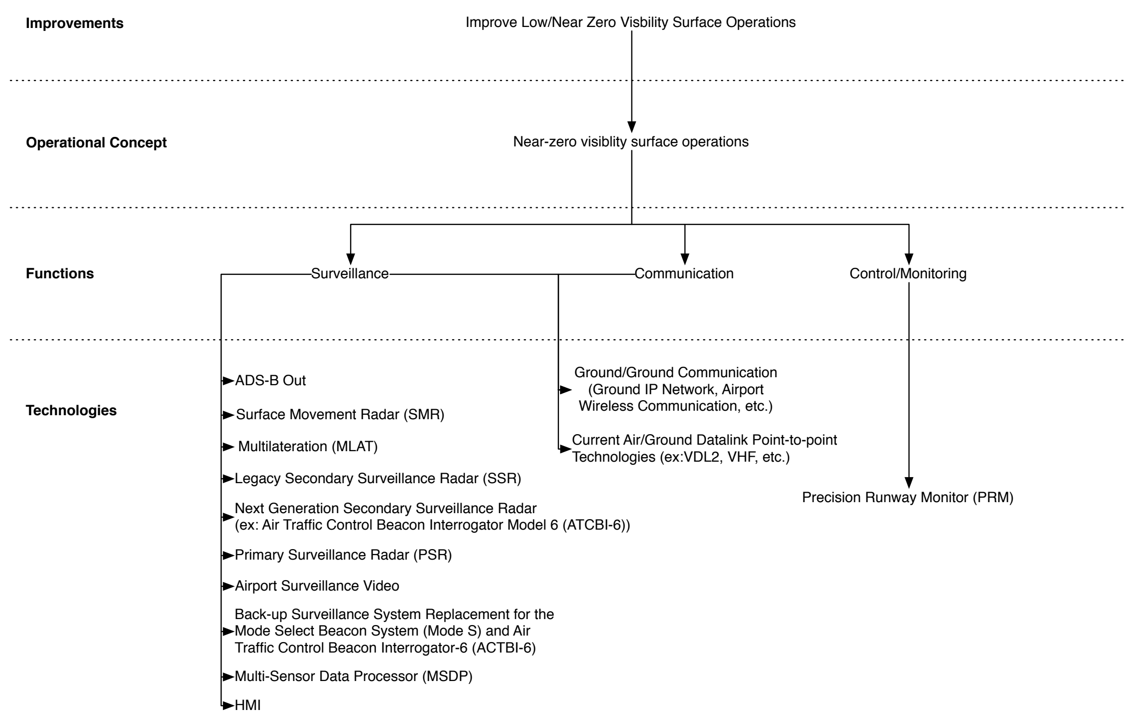


Figure B.33: Near Zero Visibility Surface Operations

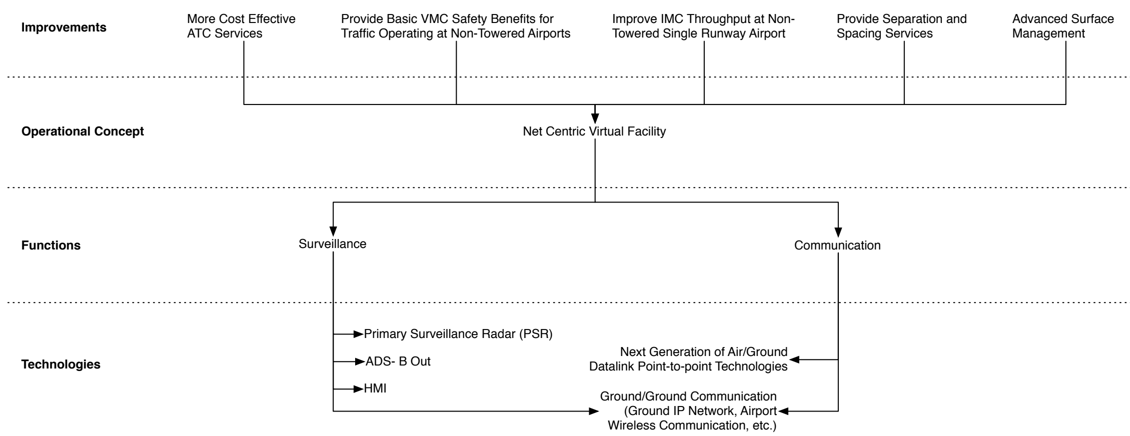


Figure B.34: Net Centric Virtual Facility

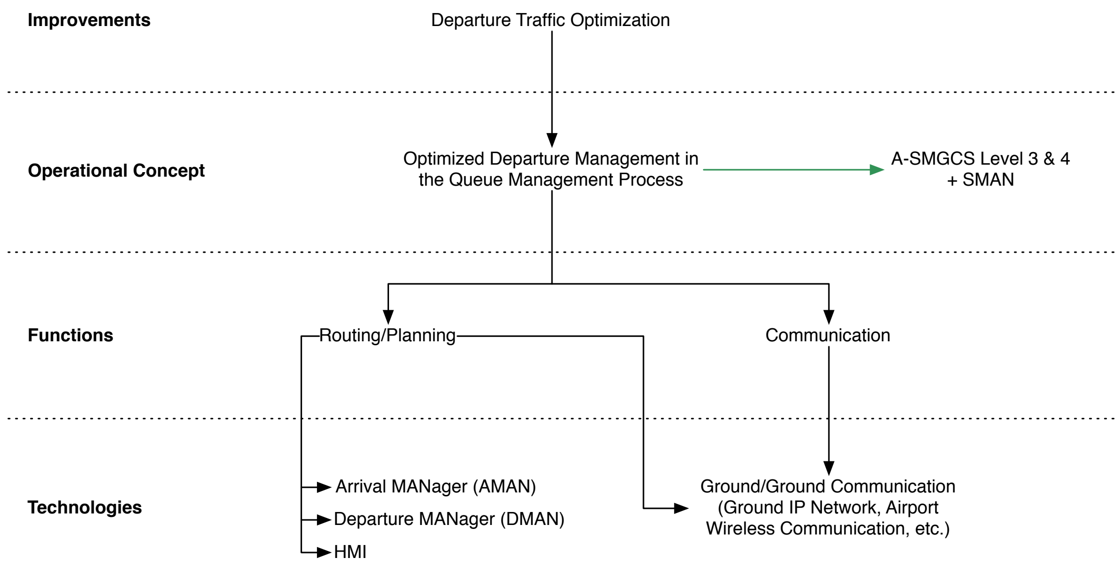


Figure B.35: Optimized Departure Management in the Queue Management Process

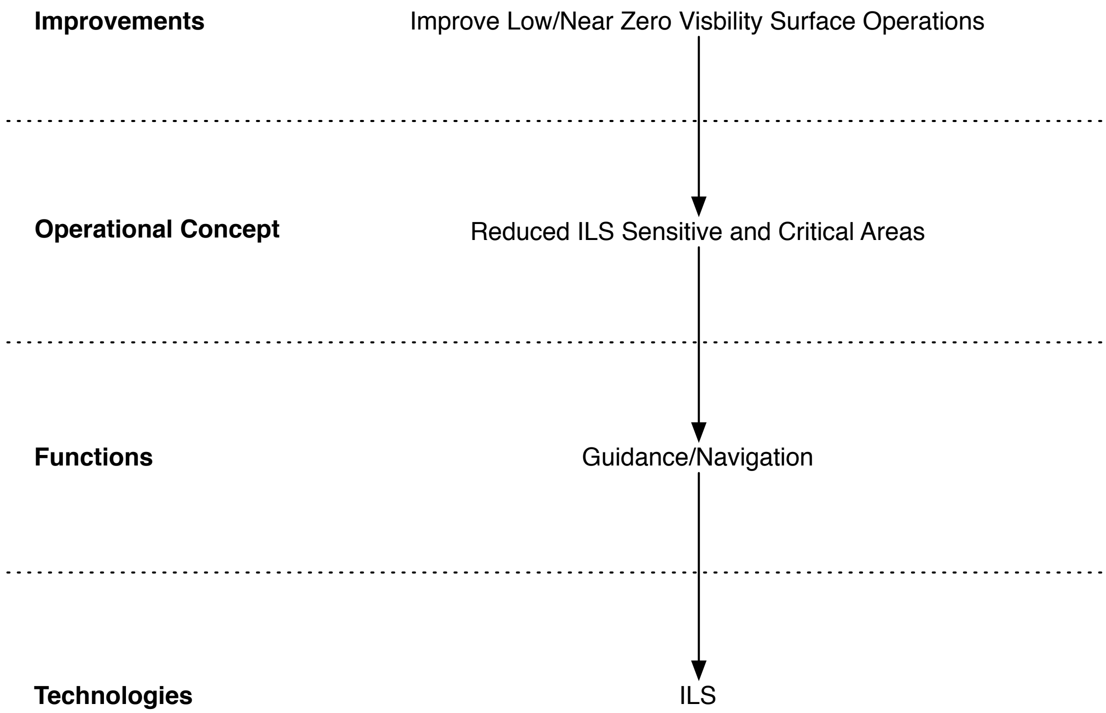


Figure B.36: Reduced ILS Sensitive and Critical Areas

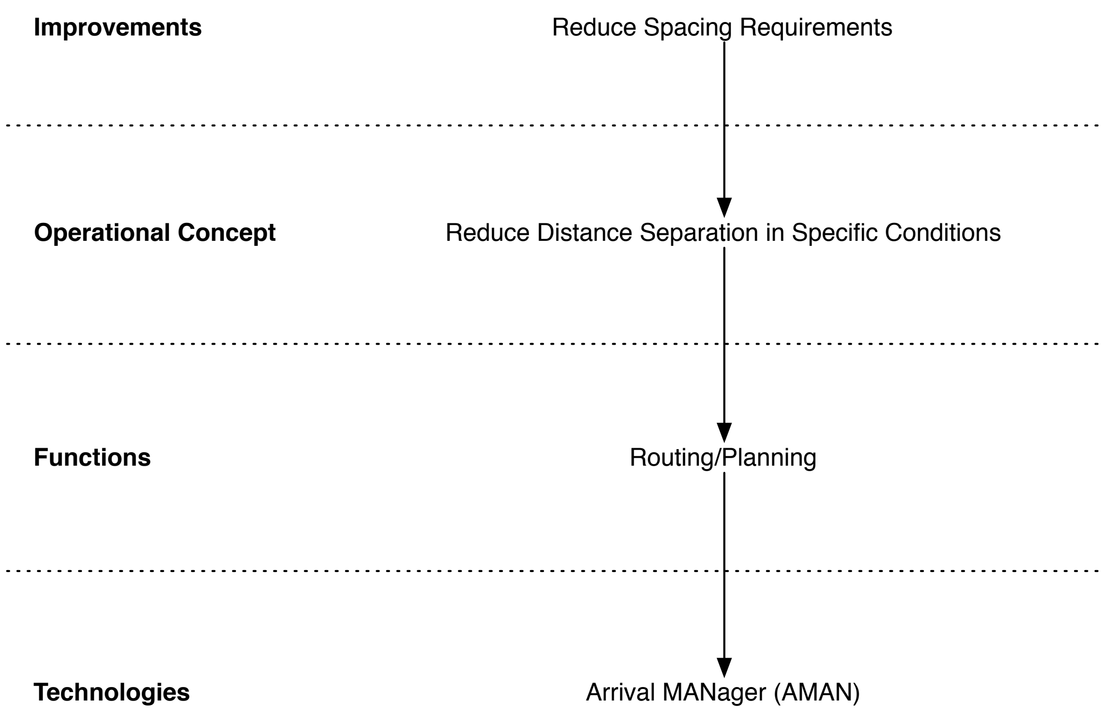


Figure B.37: Reduce Distance Separation in Specific Conditions

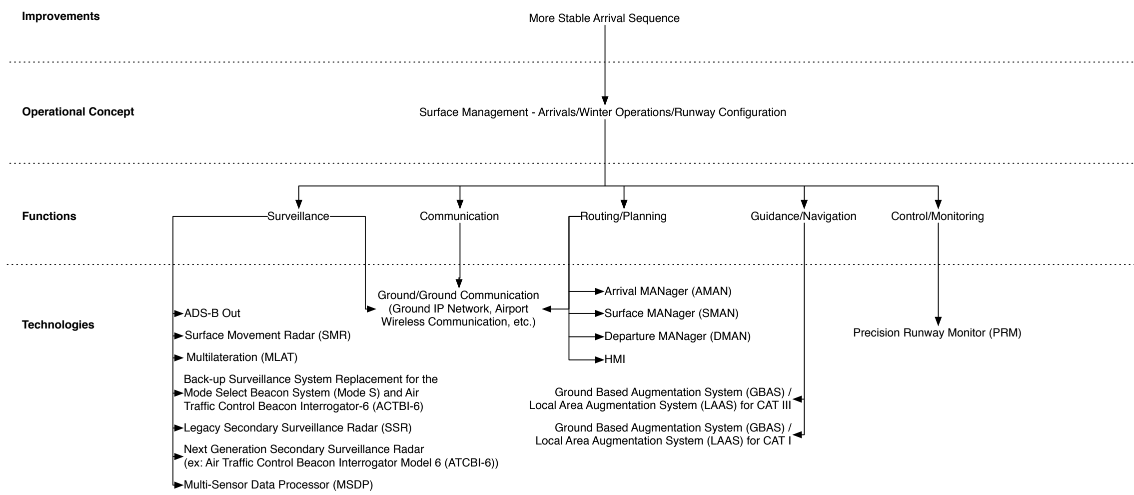


Figure B.38: Surface Management Arrivals/Winter Operations Runway Configuration

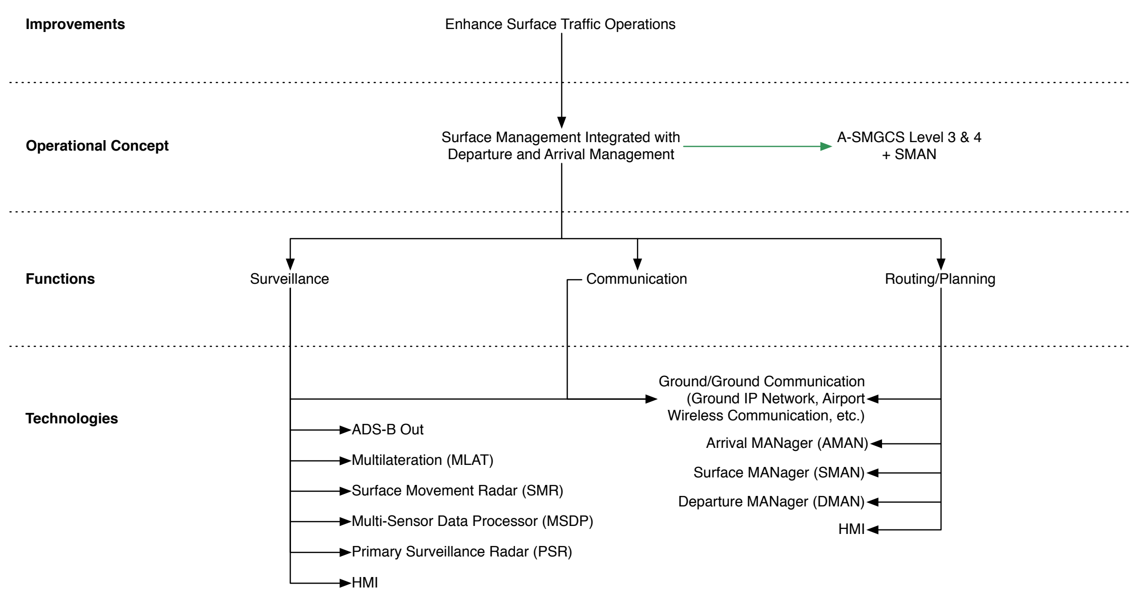


Figure B.39: Surface Management Integrated with Departure and Arrival Management

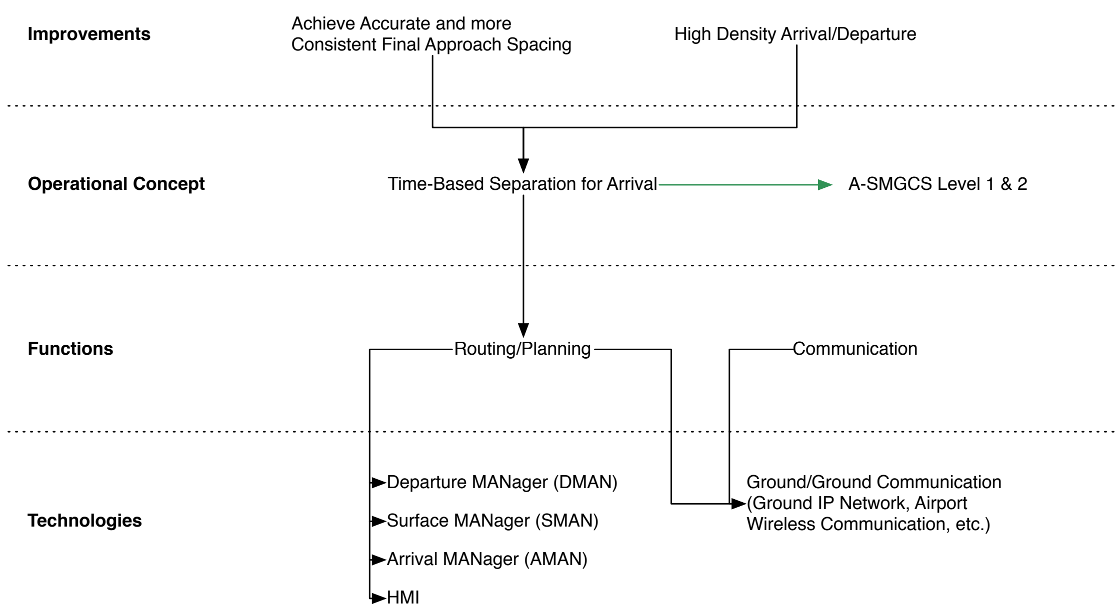


Figure B.40: Time Based Separation for Arrival

APPENDIX C

FILEWRAPPER FOR MACAD

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# Automatically Generated ScriptWrapper
# Quick Wrap Version: 2.0, build 33603
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arriving per day " units="Percent"
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arriving per day " units="Percent"
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variable: PercMEDIUMacArrivingbtw18and19 double input units="Percentage"
variable: PercMEDIUMacArrivingbtw20and21 double input units="Percentage"
variable: PercMEDIUMacArrivingbtw21and22 double input units="Percentage"
variable: PercMEDIUMacArrivingbtw22and23 double input units="Percentage"
variable: PercMEDIUMacArrivingbtw23and0 double input units="Percentage"
variable: PercLARGEacArrivingbtw0and1 double input units="Percentage"
variable: PercLARGEacArrivingbtw1and2 double input units="Percentage"
variable: PercLARGEacArrivingbtw2and3 double input units="Percentage"
variable: PercLARGEacArrivingbtw3and4 double input units="Percentage"
variable: PercLARGEacArrivingbtw4and5 double input units="Percentage"
variable: PercLARGEacArrivingbtw5and6 double input units="Percentage"
variable: PercLARGEacArrivingbtw6and7 double input units="Percentage"
variable: PercLARGEacArrivingbtw7and8 double input units="Percentage"
variable: PercLARGEacArrivingbtw8and9 double input units="Percentage"
variable: PercLARGEacArrivingbtw9and10 double input units="Percentage"
variable: PercLARGEacArrivingbtw10and11 double input units="Percentage"
variable: PercLARGEacArrivingbtw11and12 double input units="Percentage"
variable: PercLARGEacArrivingbtw12and13 double input units="Percentage"
variable: PercLARGEacArrivingbtw13and14 double input units="Percentage"
variable: PercLARGEacArrivingbtw14and15 double input units="Percentage"
variable: PercLARGEacArrivingbtw15and16 double input units="Percentage"
variable: PercLARGEacArrivingbtw16and17 double input units="Percentage"
variable: PercLARGEacArrivingbtw17and18 double input units="Percentage"
variable: PercLARGEacArrivingbtw18and19 double input units="Percentage"
variable: PercLARGEacArrivingbtw19and20 double input units="Percentage"
variable: PercLARGEacArrivingbtw20and21 double input units="Percentage"
variable: PercLARGEacArrivingbtw21and22 double input units="Percentage"
variable: PercLARGEacArrivingbtw22and23 double input units="Percentage"
variable: PercLARGEacArrivingbtw23and0 double input units="Percentage"
variable: PercWIDEacArrivingbtw0and1 double input units="Percentage"
variable: PercWIDEacArrivingbtw1and2 double input units="Percentage"
variable: PercWIDEacArrivingbtw2and3 double input units="Percentage"
variable: PercWIDEacArrivingbtw3and4 double input units="Percentage"
variable: PercWIDEacArrivingbtw4and5 double input units="Percentage"
variable: PercWIDEacArrivingbtw5and6 double input units="Percentage"
variable: PercWIDEacArrivingbtw6and7 double input units="Percentage"
variable: PercWIDEacArrivingbtw7and8 double input units="Percentage"
variable: PercWIDEacArrivingbtw8and9 double input units="Percentage"
variable: PercWIDEacArrivingbtw9and10 double input units="Percentage"
variable: PercWIDEacArrivingbtw10and11 double input units="Percentage"
variable: PercWIDEacArrivingbtw11and12 double input units="Percentage"
variable: PercWIDEacArrivingbtw12and13 double input units="Percentage"
variable: PercWIDEacArrivingbtw13and14 double input units="Percentage"
variable: PercWIDEacArrivingbtw14and15 double input units="Percentage"
variable: PercWIDEacArrivingbtw15and16 double input units="Percentage"
variable: PercWIDEacArrivingbtw16and17 double input units="Percentage"
variable: PercWIDEacArrivingbtw17and18 double input units="Percentage"
variable: PercWIDEacArrivingbtw18and19 double input units="Percentage"
variable: PercWIDEacArrivingbtw19and20 double input units="Percentage"
variable: PercWIDEacArrivingbtw20and21 double input units="Percentage"
variable: PercWIDEacArrivingbtw21and22 double input units="Percentage"
variable: PercWIDEacArrivingbtw22and23 double input units="Percentage"
variable: PercWIDEacArrivingbtw23and0 double input units="Percentage"
variable: PercJUMBOacArrivingbtw0and1 double input units="Percentage"
variable: PercJUMBOacArrivingbtw1and2 double input units="Percentage"
variable: PercJUMBOacArrivingbtw2and3 double input units="Percentage"
variable: PercJUMBOacArrivingbtw3and4 double input units="Percentage"
variable: PercJUMBOacArrivingbtw4and5 double input units="Percentage"
variable: PercJUMBOacArrivingbtw5and6 double input units="Percentage"
variable: PercJUMBOacArrivingbtw6and7 double input units="Percentage"
variable: PercJUMBOacArrivingbtw7and8 double input units="Percentage"
variable: PercJUMBOacArrivingbtw8and9 double input units="Percentage"
variable: PercJUMBOacArrivingbtw9and10 double input units="Percentage"
variable: PercJUMBOacArrivingbtw10and11 double input units="Percentage"
variable: PercJUMBOacArrivingbtw11and12 double input units="Percentage"
```

```
variable: PercJUMBOacArrivingbtw12and13 double input units="Percentage"
variable: PercJUMBOacArrivingbtw13and14 double input units="Percentage"
variable: PercJUMBOacArrivingbtw14and15 double input units="Percentage"
variable: PercJUMBOacArrivingbtw15and16 double input units="Percentage"
variable: PercJUMBOacArrivingbtw16and17 double input units="Percentage"
variable: PercJUMBOacArrivingbtw17and18 double input units="Percentage"
variable: PercJUMBOacArrivingbtw18and19 double input units="Percentage"
variable: PercJUMBOacArrivingbtw19and20 double input units="Percentage"
variable: PercJUMBOacArrivingbtw20and21 double input units="Percentage"
variable: PercJUMBOacArrivingbtw21and22 double input units="Percentage"
variable: PercJUMBOacArrivingbtw22and23 double input units="Percentage"
variable: PercJUMBOacArrivingbtw23and0 double input units="Percentage"
variable: PercMEDIUMacArrivingbtw19and20 double input
variable: ArrRunwayOccTimeforSMALLacinsec double input units="sec"
variable: ArrRunwayOccTimeforMEDIUMacinsec double input units="sec"
variable: ArrRunwayOccTimeforLARGEacinsec double input units="sec"
variable: ArrRunwayOccTimeforWIDEacinsec double input units="sec"
variable: ArrRunwayOccTimeforJUMBOacinsec double input units="sec"
variable: DepRunwayOccTimeforSMALLacinsec double input units="sec"
variable: DepRunwayOccTimeforMEDIUMacinsec double input units="sec"
variable: DepRunwayOccTimeforLARGEacinsec double input units="sec"
variable: DepRunwayOccTimeforWIDEacinsec double input units="sec"
variable: DepRunwayOccTimeforJUMBOacinsec double input units="sec"

script: language="java"

void run()
{
   wrapper.getRunShare().lock();
   generate();
   execute();
   parse();
}

/**************************************************
 * DO NOT EDIT BEYOND THIS POINT
 * Code beyond this point is generated by the
 * FileWrapper Editor.  Changes will be lost
 * the next time changes are made.
 **************************************************/

wrapper.requireAnalysisServerVersion(6, 2);

//[UseRelativeFolders="false" BackupOutputFilesEachRun="true"]

//Runshare Definitions
wrapper.getRunShare().setMode(PHXRunShareContext.MODE_NONE);
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\Master.in.template");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\AircraftTypes.inr.template"
);
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\RunwayConfigurations.rcf.te
mplate");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\HourlyConfiguration.hcf.tem
plate");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\Schedule.ags.template");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Output\\statistics.out");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\RunwaySet0.rst.template");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\RunwaySet0.out.macad");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\Master.in");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\AircraftTypes.inr");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\RunwayConfigurations.rcf");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\HourlyConfiguration.hcf");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\Schedule.ags");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\RunwaySet0.rst");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\Aprons.apr.template");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Input\\Aprons.apr");
wrapper.getRunShare().addFileToCopy("C:\\MACAD2bis\\Output\\RunSets.rso");
```

```
//File: rowFieldInMaster_in
//[fileDefinition="IBHVG2"]
PHXRowFieldFile rowFieldInMaster_in = new PHXRowFieldFile(wrapper);
rowFieldInMaster_in.setTemplateFile("C:\\MACAD2bis\\Input\\Master.in.template");
rowFieldInMaster_in.setFileToGenerate("C:\\MACAD2bis\\Input\\Master.in");
rowFieldInMaster_in.setDelimiters(" \t,=");



rowFieldInMaster_in.readTemplate();

//File: rowFieldInAircraftTypes_inr
//[fileDefinition="IBHVG2"]
PHXRowFieldFile rowFieldInAircraftTypes_inr = new PHXRowFieldFile(wrapper);
rowFieldInAircraftTypes_inr.setTemplateFile("C:\\MACAD2bis\\Input\\AircraftTypes.inr.t
emplate");
rowFieldInAircraftTypes_inr.setFileToGenerate("C:\\MACAD2bis\\Input\\AircraftTypes.inr
");
rowFieldInAircraftTypes_inr.setDelimiters(" \t=,:");



rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeDomesticSMALLac","in
t",true,"top|r8c2[ \\t=,:]","min","Average turn around time on aviobridge stands for
domestic flights with SMALL aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeDomesticMEDIUMac","i
nt",true,"top|r9c2[ \\t=,:]","min","Average turn around time on aviobridge stands for
domestic flights with MEDIUM aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeDomesticLARGEac","in
t",true,"top|r10c2[ \\t=,:]","min","Average turn around time on aviobridge stands for
domestic flights with LARGE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeDomesticWIDEac","int
",true,"top|r11c2[ \\t=,:]","min","Average turn around time on aviobridge stands for
domestic flights with WIDE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeDomesticJUMBOac","in
t",true,"top|r12c2[ \\t=,:]","min","Average turn around time on aviobridge stands for
domestic flights with JUMBO aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeDomesticSMALLac",
"int",true,"top|r8c3[ \\t=,:]","min","Standard Deviation for turn around time on
aviobridge stands for domestic flights with SMALL aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeDomesticMEDIUMac"
,"int",true,"top|r9c3[ \\t=,:]","min","Standard Deviation for turn around time on
aviobridge stands for domestic flights with MEDIUM aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeDomesticLARGEac",
"int",true,"top|r10c3[ \\t=,:]","min","Standard Deviation for turn around time on
aviobridge stands for domestic flights with LARGE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeDomesticWIDEac","
int",true,"top|r11c3[ \\t=,:]","min","Standard Deviation for turn around time on
aviobridge stands for domestic flights with WIDE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeDomesticJUMBOac",
"int",true,"top|r12c3[ \\t=,:]","min","Standard Deviation for turn around time on
aviobridge stands for domestic flights with JUMBO aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeInternationalSMALLac
","int",true,"top|r8c4[ \\t=,:]","min","Average turn around time on aviobridge stands
for international flights with SMALL aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeInternationalMEDIUMa
c","int",true,"top|r9c4[ \\t=,:]","min","Average turn around time on aviobridge stands
for international flights with MEDIUM aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeInternationalLARGEac
","int",true,"top|r10c4[ \\t=,:]","min","Average turn around time on aviobridge stands
for international flights with LARGE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeInternationalWIDEac"
,"int",true,"top|r11c4[ \\t=,:]","min","Average turn around time on aviobridge stands
for international flights with WIDE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesAviobridgeInternationalJUMBOac
","int",true,"top|r12c4[ \\t=,:]","min","Average turn around time on aviobridge stands
for international flights with JUMBO aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeInternationalSMAL
```

```
Lac","int",true,"top|r8c5[ \\t=,:]","min","Standard deviation for turn around time on
aviobridge stands for international flights with SMALL aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeInternationalMEDI
UMac","int",true,"top|r9c5[ \\t=,:]","min","Standard deviation for turn around time on
aviobridge stands for international flights with MEDIUM aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeInternationalLARG
Eac","int",true,"top|r10c5[ \\t=,:]","min","Standard deviation for turn around time on
aviobridge stands for international flights with LARGE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeInternationalWIDE
ac","int",true,"top|r11c5[ \\t=,:]","min","Standard deviation for turn around time on
aviobridge stands for international flights with WIDE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesAviobridgeInternationalJUMB
Oac","int",true,"top|r12c5[ \\t=,:]","min","Standard deviation for turn around time on
aviobridge stands for international flights with JUMBO aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteDomesticSMALLac","int",t
rue,"top|r8c6[ \\t=,:]","min","Average turn around time on remote stands for domestic
flights with SMALL aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteDomesticMEDIUMac","int",
true,"top|r9c6[ \\t=,:]","min","Average turn around time on remote stands for domestic
flights with MEDIUM aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteDomesticLARGEac","int",t
rue,"top|r10c6[ \\t=,:]","min","Average turn around time on remote stands for domestic
flights with LARGE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteDomesticWIDEac","int",tr
ue,"top|r11c6[ \\t=,:]","min","Average turn around time on remote stands for domestic
flights with WIDE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteDomesticJUMBOac","int",t
rue,"top|r12c6[ \\t=,:]","min","Average turn around time on remote stands for domestic
flights with JUMBO aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteDomesticSMALLac","int
",true,"top|r8c7[ \\t=,:]","min","Standard Deviation for turn around time on remote
stands for domestic flights with SMALL aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteDomesticMEDIUMac","in
t",true,"top|r9c7[ \\t=,:]","min","Standard Deviation for turn around time on remote
stands for domestic flights with MEDIUM aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteDomesticLARGEac","int
",true,"top|r10c7[ \\t=,:]","min","Standard Deviation for turn around time on remote
stands for domestic flights with LARGE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteDomesticWIDEac","int"
,true,"top|r11c7[ \\t=,:]","min","Standard Deviation for turn around time on remote
stands for domestic flights with WIDE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteDomesticJUMBOac","int
",true,"top|r12c7[ \\t=,:]","min","Standard Deviation for turn around time on remote
stands for domestic flights with JUMBO aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteInternationalSMALLac","i
nt",true,"top|r8c8[ \\t=,:]","min","Average turn around time on remote stands for
international flights with SMALL aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteInternationalMEDIUMac","
int",true,"top|r9c8[ \\t=,:]","min","Average turn around time on remote stands for
international flights with MEDIUM aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteInternationalLARGEac","i
nt",true,"top|r10c8[ \\t=,:]","min","Average turn around time on remote stands for
international flights with LARGE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteInternationalWIDEac","in
t",true,"top|r11c8[ \\t=,:]","min","Average turn around time on remote stands for
international flights with WIDE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("AvTurnAroundTimesRemoteInternationalJUMBOac","i
nt",true,"top|r12c8[ \\t=,:]","min","Average turn around time on remote stands for
international flights with JUMBO aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteInternationalSMALLac"
,"int",true,"top|r8c9[ \\t=,:]","min","Standard deviation for turn around time on
remote stands for international flights with SMALL aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteInternationalMEDIUMac
","int",true,"top|r9c9[ \\t=,:]","min","Standard deviation for turn around time on
remote stands for international flights with MEDIUM aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteInternationalLARGEac"
,"int",true,"top|r10c9[ \\t=,:]","min","Standard deviation for turn around time on
remote stands for international flights with LARGE aircraft","","","","","","");
```

```
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteInternationalWIDEac",
"int",true,"top|r11c9[ \\t=,:]","min","Standard deviation for turn around time on
remote stands for international flights with WIDE aircraft","","","","","","");
rowFieldInAircraftTypes_inr.defineVar("StDevTurnAroundTimesRemoteInternationalJUMBOac"
,"int",true,"top|r12c9[ \\t=,:]","min","Standard deviation for turn around time on
remote stands for international flights with JUMBO aircraft","","","","","","");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeDomesticSMALLac","
30");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeDomesticMEDIUMac",
"40");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeDomesticLARGEac","
42");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeDomesticWIDEac","4
5");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeDomesticJUMBOac","
50");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeDomesticSMALLac
","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeDomesticMEDIUMa
c","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeDomesticLARGEac
","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeDomesticWIDEac"
,"10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeDomesticJUMBOac
","10");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeInternationalSMALL
ac","30");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeInternationalMEDIU
Mac","40");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeInternationalLARGE
ac","42");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeInternationalWIDEa
c","45");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesAviobridgeInternationalJUMBO
ac","50");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeInternationalSM
ALLac","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeInternationalME
DIUMac","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeInternationalLA
RGEac","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeInternationalWI
DEac","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesAviobridgeInternationalJU
MBOac","10");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteDomesticSMALLac","30")
;
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteDomesticMEDIUMac","40"
);
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteDomesticLARGEac","42")
;
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteDomesticWIDEac","45");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteDomesticJUMBOac","50")
;
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteDomesticSMALLac","1
0");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteDomesticMEDIUMac","
10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteDomesticLARGEac","1
0");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteDomesticWIDEac","10
");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteDomesticJUMBOac","1
0");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteInternationalSMALLac",
"30");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteInternationalMEDIUMac"
```

```
,"40");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteInternationalLARGEac",
"42");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteInternationalWIDEac","
45");
rowFieldInAircraftTypes_inr.setVariable("AvTurnAroundTimesRemoteInternationalJUMBOac",
"50");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteInternationalSMALLa
c","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteInternationalMEDIUM
ac","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteInternationalLARGEa
c","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteInternationalWIDEac
","10");
rowFieldInAircraftTypes_inr.setVariable("StDevTurnAroundTimesRemoteInternationalJUMBOa
c","10");
rowFieldInAircraftTypes_inr.readTemplate();

//File: rowFieldInRunwayConfigurations_rcf
//[fileDefinition="Name-Value"]
PHXRowFieldFile rowFieldInRunwayConfigurations_rcf = new PHXRowFieldFile(wrapper);
rowFieldInRunwayConfigurations_rcf.setTemplateFile("C:\\MACAD2bis\\Input\\RunwayConfig
urations.rcf.template");
rowFieldInRunwayConfigurations_rcf.setFileToGenerate("C:\\MACAD2bis\\Input\\RunwayConf
igurations.rcf");
rowFieldInRunwayConfigurations_rcf.setDelimiters(" \t=,:");



rowFieldInRunwayConfigurations_rcf.defineVar("ArrivalsTaxiAverage","double",true,"top|
r6c5[ \\t=,:]","min","Arrivals taxi average","","","","","","");
rowFieldInRunwayConfigurations_rcf.defineVar("ArrivalsTaxiStDev","double",true,"top|r6
c6[ \\t=,:]","min","Arrivals taxi standard deviation","","","","","","");
rowFieldInRunwayConfigurations_rcf.defineVar("DepTaxiAverage","double",true,"top|r6c7[
\\t=,:]","min","Departures taxi average","","","","","","");
rowFieldInRunwayConfigurations_rcf.defineVar("DepTaxiStDev","double",true,"top|r6c8[
\\t=,:]","min","Departures taxi standard deviation","","","","","","");
rowFieldInRunwayConfigurations_rcf.defineVar("pronBufferCapacity","int",true,"top|r7c1
[ \\t=,:]","aircraft","Apron buffer capacity","","","","","","");
rowFieldInRunwayConfigurations_rcf.defineVar("RunwaySetType2","int",true,"top|r6c1[
\\t=,:]","","Runway set type","","","","","","");
rowFieldInRunwayConfigurations_rcf.defineVar("Sequencing","int",true,"top|r6c2[
\\t=,:]","","Sequencing (0:No, 1:Yes) (structure of file changes)","","","","","","");
rowFieldInRunwayConfigurations_rcf.defineVar("RunwayConfiguration","int",true,"top|r7c
2[ \\t=,:]","","Runway configuration","","","","","","");
rowFieldInRunwayConfigurations_rcf.setVariable("ArrivalsTaxiAverage","5.0");
rowFieldInRunwayConfigurations_rcf.setVariable("ArrivalsTaxiStDev","2.0");
rowFieldInRunwayConfigurations_rcf.setVariable("DepTaxiAverage","9.0");
rowFieldInRunwayConfigurations_rcf.setVariable("DepTaxiStDev","2.0");
rowFieldInRunwayConfigurations_rcf.setVariable("pronBufferCapacity","13");
rowFieldInRunwayConfigurations_rcf.setVariable("RunwaySetType2","1");
rowFieldInRunwayConfigurations_rcf.setVariable("Sequencing","0");
rowFieldInRunwayConfigurations_rcf.setVariable("RunwayConfiguration","1");
rowFieldInRunwayConfigurations_rcf.readTemplate();

//File: rowFieldInHourlyConfiguration_hcf
//[fileDefinition="Name-Value"]
PHXRowFieldFile rowFieldInHourlyConfiguration_hcf = new PHXRowFieldFile(wrapper);
rowFieldInHourlyConfiguration_hcf.setTemplateFile("C:\\MACAD2bis\\Input\\HourlyConfigu
ration.hcf.template");
rowFieldInHourlyConfiguration_hcf.setFileToGenerate("C:\\MACAD2bis\\Input\\HourlyConfi
guration.hcf");
rowFieldInHourlyConfiguration_hcf.setDelimiters(" \t=,:");



rowFieldInHourlyConfiguration_hcf.readTemplate();
```

```
//File: rowFieldInSchedule_ags
//[fileDefinition="Name-Value"]
PHXRowFieldFile rowFieldInSchedule_ags = new PHXRowFieldFile(wrapper);
rowFieldInSchedule_ags.setTemplateFile("C:\\MACAD2bis\\Input\\Schedule.ags.template");
rowFieldInSchedule_ags.setFileToGenerate("C:\\MACAD2bis\\Input\\Schedule.ags");
rowFieldInSchedule_ags.setDelimiters(" \t=,:");



rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw0and1","int",true,"top|r11c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw1and2","int",true,"top|r12c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw2and3","int",true,"top|r13c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw3and4","int",true,"top|r14c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw4and5","int",true,"top|r15c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw5and6","int",true,"top|r16c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw6and7","int",true,"top|r17c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw7and8","int",true,"top|r18c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw8and9","int",true,"top|r19c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw9and10","int",true,"top|r20c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw10and11","int",true,"top|r21c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw11and12","int",true,"top|r22c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw12and13","int",true,"top|r23c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw13and14","int",true,"top|r24c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw14and15","int",true,"top|r25c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw15and16","int",true,"top|r26c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw16and17","int",true,"top|r27c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw17and18","int",true,"top|r28c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw18and19","int",true,"top|r29c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw19and20","int",true,"top|r30c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw20and21","int",true,"top|r31c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw21and22","int",true,"top|r32c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw22and23","int",true,"top|r33c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingbtw23and24","int",true,"top|r34c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbSMALLacArrivingOvernight","int",true,"top|r35c2[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw0and1","int",true,"top|r11c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw1and2","int",true,"top|r12c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw2and3","int",true,"top|r13c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw3and4","int",true,"top|r14c3[
\\t=,:]","aircraft","","","","","","","");
```

```
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw4and5","int",true,"top|r15c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw5and6","int",true,"top|r16c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw6and7","int",true,"top|r17c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw7and8","int",true,"top|r18c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw8and9","int",true,"top|r19c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw9and10","int",true,"top|r20c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw10and11","int",true,"top|r21c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw11and12","int",true,"top|r22c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw12and13","int",true,"top|r23c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw13and14","int",true,"top|r24c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw14and15","int",true,"top|r25c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw15and16","int",true,"top|r26c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw16and17","int",true,"top|r27c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw17and18","int",true,"top|r28c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw18and19","int",true,"top|r29c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw19and20","int",true,"top|r30c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw20and21","int",true,"top|r31c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw21and22","int",true,"top|r32c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw22and23","int",true,"top|r33c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingbtw23and24","int",true,"top|r34c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbMEDIUMacArrivingOvernight","int",true,"top|r35c3[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw0and1","int",true,"top|r11c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw1and2","int",true,"top|r12c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw2and3","int",true,"top|r13c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw3and4","int",true,"top|r14c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw4and5","int",true,"top|r15c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw5and6","int",true,"top|r16c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw6and7","int",true,"top|r17c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw7and8","int",true,"top|r18c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw8and9","int",true,"top|r19c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw9and10","int",true,"top|r20c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw10and11","int",true,"top|r21c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw11and12","int",true,"top|r22c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw12and13","int",true,"top|r23c4[
\\t=,:]","aircraft","","","","","","","");
```

```
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw13and14","int",true,"top|r24c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw14and15","int",true,"top|r25c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw15and16","int",true,"top|r26c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw16and17","int",true,"top|r27c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw17and18","int",true,"top|r28c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw18and19","int",true,"top|r29c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw19and20","int",true,"top|r30c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw20and21","int",true,"top|r31c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw21and22","int",true,"top|r32c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw22and23","int",true,"top|r33c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingbtw23and24","int",true,"top|r34c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbLARGEacArrivingOvernight","int",true,"top|r35c4[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw0and1","int",true,"top|r11c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw1and2","int",true,"top|r12c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw2and3","int",true,"top|r13c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw3and4","int",true,"top|r14c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw4and5","int",true,"top|r15c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw5and6","int",true,"top|r16c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw6and7","int",true,"top|r17c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw7and8","int",true,"top|r18c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw8and9","int",true,"top|r19c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw9and10","int",true,"top|r20c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw10and11","int",true,"top|r21c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw11and12","int",true,"top|r22c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw12and13","int",true,"top|r23c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw13and14","int",true,"top|r24c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw14and15","int",true,"top|r25c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw15and16","int",true,"top|r26c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw16and17","int",true,"top|r27c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw17and18","int",true,"top|r28c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw18and19","int",true,"top|r29c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw19and20","int",true,"top|r30c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw20and21","int",true,"top|r31c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw21and22","int",true,"top|r32c5[
\\t=,:]","aircraft","","","","","","","");
```

```
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw22and23","int",true,"top|r33c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingbtw23and24","int",true,"top|r34c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbWIDEacArrivingOvernight","int",true,"top|r35c5[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw0and1","int",true,"top|r11c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw1and2","int",true,"top|r12c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw2and3","int",true,"top|r13c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw3and4","int",true,"top|r14c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw4and5","int",true,"top|r15c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw5and6","int",true,"top|r16c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw6and7","int",true,"top|r17c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw7and8","int",true,"top|r18c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw8and9","int",true,"top|r19c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw9and10","int",true,"top|r20c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw10and11","int",true,"top|r21c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw11and12","int",true,"top|r22c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw12and13","int",true,"top|r23c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw13and14","int",true,"top|r24c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw14and15","int",true,"top|r25c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw15and16","int",true,"top|r26c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw16and17","int",true,"top|r27c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw17and18","int",true,"top|r28c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw18and19","int",true,"top|r29c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw19and20","int",true,"top|r30c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw20and21","int",true,"top|r31c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw21and22","int",true,"top|r32c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw22and23","int",true,"top|r33c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingbtw23and24","int",true,"top|r34c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("NbJUMBOacArrivingOvernight","int",true,"top|r35c6[
\\t=,:]","aircraft","","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw0and1","int
",true,"top|r11c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart after
arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw1and2","int
",true,"top|r12c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart after
arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw2and3","int
",true,"top|r13c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart after
arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw3and4","int
",true,"top|r14c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart after
arrival between 3 and 4 hour","","","","","","");
```

```
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw4and5","int
",true,"top|r15c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart after
arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw5and6","int
",true,"top|r16c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart after
arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw6and7","int
",true,"top|r17c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart after
arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw7and8","int
",true,"top|r18c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart after
arrival between 7 and 8 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw8and9","int
",true,"top|r19c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart after
arrival between 8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw9and10","in
t",true,"top|r20c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw10and11","i
nt",true,"top|r21c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw11and12","i
nt",true,"top|r22c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw12and13","i
nt",true,"top|r23c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw13and14","i
nt",true,"top|r24c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw14and15","i
nt",true,"top|r25c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 14 and 15 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw15and16","i
nt",true,"top|r26c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 15 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw16and17","i
nt",true,"top|r27c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw17and18","i
nt",true,"top|r28c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw18and19","i
nt",true,"top|r29c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw19and20","i
nt",true,"top|r30c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw20and21","i
nt",true,"top|r31c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw21and22","i
nt",true,"top|r32c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 21 and 22 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw22and23","i
nt",true,"top|r33c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrbtw23and24","i
nt",true,"top|r34c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeSMALLacScheduledtoDepartafterArrOvernight","in
t",true,"top|r35c7[ \\t=,:]","min","Average time SMALL ac are scheduled to depart
after arrival overnight","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw0and1","in
t",true,"top|r11c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw1and2","in
t",true,"top|r12c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
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after arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw2and3","in
t",true,"top|r13c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw3and4","in
t",true,"top|r14c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 3 and 4 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw4and5","in
t",true,"top|r15c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw5and6","in
t",true,"top|r16c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw6and7","in
t",true,"top|r17c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw7and8","in
t",true,"top|r18c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 7 and 8 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw8and9","in
t",true,"top|r19c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw9and10","i
nt",true,"top|r20c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw10and11","
int",true,"top|r21c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw11and12","
int",true,"top|r22c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw12and13","
int",true,"top|r23c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw13and14","
int",true,"top|r24c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw14and15","
int",true,"top|r25c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 14 and 15 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw15and16","
int",true,"top|r26c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 15 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw16and17","
int",true,"top|r27c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw17and18","
int",true,"top|r28c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw18and19","
int",true,"top|r29c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw19and20","
int",true,"top|r30c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw20and21","
int",true,"top|r31c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw21and22","
int",true,"top|r32c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 21 and 22 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw22and23","
int",true,"top|r33c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrbtw23and24","
int",true,"top|r34c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeMEDIUMacScheduledtoDepartafterArrOvernight","i
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nt",true,"top|r35c9[ \\t=,:]","min","Average time MEDIUM ac are scheduled to depart
after arrival overnight","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw0and1","int
",true,"top|r11c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw1and2","int
",true,"top|r12c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw2and3","int
",true,"top|r13c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw3and4","int
",true,"top|r14c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 3 and 4 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw4and5","int
",true,"top|r15c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw5and6","int
",true,"top|r16c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw6and7","int
",true,"top|r17c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw7and8","int
",true,"top|r18c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 7 and 8 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw8and9","int
",true,"top|r19c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw9and10","in
t",true,"top|r20c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw10and11","i
nt",true,"top|r21c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw11and12","i
nt",true,"top|r22c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw12and13","i
nt",true,"top|r23c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw13and14","i
nt",true,"top|r24c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw14and15","i
nt",true,"top|r25c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 14 and 15 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw15and16","i
nt",true,"top|r26c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 15 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw16and17","i
nt",true,"top|r27c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw17and18","i
nt",true,"top|r28c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw18and19","i
nt",true,"top|r29c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw19and20","i
nt",true,"top|r30c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw20and21","i
nt",true,"top|r31c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw21and22","i
nt",true,"top|r32c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 21 and 22 hour","","","","","","");
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rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw22and23","i
nt",true,"top|r33c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrbtw23and24","i
nt",true,"top|r34c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeLARGEacScheduledtoDepartafterArrOvernight","in
t",true,"top|r35c11[ \\t=,:]","min","Average time LARGE ac are scheduled to depart
after arrival overnight","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw0and1","int"
,true,"top|r11c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw1and2","int"
,true,"top|r12c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw2and3","int"
,true,"top|r13c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw3and4","int"
,true,"top|r14c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 3 and 4 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw4and5","int"
,true,"top|r15c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw5and6","int"
,true,"top|r16c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw6and7","int"
,true,"top|r17c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw7and8","int"
,true,"top|r18c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 7 and 8 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw8and9","int"
,true,"top|r19c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw9and10","int
",true,"top|r20c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw10and11","in
t",true,"top|r21c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw11and12","in
t",true,"top|r22c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw12and13","in
t",true,"top|r23c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw13and14","in
t",true,"top|r24c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw14and15","in
t",true,"top|r25c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 14 and 15 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw15and16","in
t",true,"top|r26c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 15 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw16and17","in
t",true,"top|r27c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw17and18","in
t",true,"top|r28c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw18and19","in
t",true,"top|r29c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw19and20","in
t",true,"top|r30c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
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after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw20and21","in
t",true,"top|r31c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw21and22","in
t",true,"top|r32c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 21 and 22 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw22and23","in
t",true,"top|r33c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrbtw23and24","in
t",true,"top|r34c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart
after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeWIDEacScheduledtoDepartafterArrOvernight","int
",true,"top|r35c13[ \\t=,:]","min","Average time WIDE ac are scheduled to depart after
arrival overnight","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw0and1","int
",true,"top|r11c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw1and2","int
",true,"top|r12c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw2and3","int
",true,"top|r13c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw3and4","int
",true,"top|r14c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 3 and 4 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw4and5","int
",true,"top|r15c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw5and6","int
",true,"top|r16c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw6and7","int
",true,"top|r17c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw7and8","int
",true,"top|r18c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 7 and 8 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw8and9","int
",true,"top|r19c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw9and10","in
t",true,"top|r20c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw10and11","i
nt",true,"top|r21c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw11and12","i
nt",true,"top|r22c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw12and13","i
nt",true,"top|r23c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw13and14","i
nt",true,"top|r24c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw14and15","i
nt",true,"top|r25c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 14 and 15 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw15and16","i
nt",true,"top|r26c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 15 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw16and17","i
nt",true,"top|r27c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw17and18","i
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nt",true,"top|r28c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw18and19","i
nt",true,"top|r29c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw19and20","i
nt",true,"top|r30c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw20and21","i
nt",true,"top|r31c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw21and22","i
nt",true,"top|r32c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 21 and 22 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw22and23","i
nt",true,"top|r33c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrbtw23and24","i
nt",true,"top|r34c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("AvTimeJUMBOacScheduledtoDepartafterArrOvernight","in
t",true,"top|r35c15[ \\t=,:]","min","Average time JUMBO ac are scheduled to depart
after arrival overnight","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw0and1","
double",true,"top|r11c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw1and2","
double",true,"top|r12c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw2and3","
double",true,"top|r13c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw3and4","
double",true,"top|r14c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 3 and 4 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw4and5","
double",true,"top|r15c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw5and6","
double",true,"top|r16c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw6and7","
double",true,"top|r17c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw7and8","
double",true,"top|r18c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 7 and 8 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw8and9","
double",true,"top|r19c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw9and10",
"double",true,"top|r20c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw10and11"
,"double",true,"top|r21c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw11and12"
,"double",true,"top|r22c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw12and13"
,"double",true,"top|r23c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw13and14"
,"double",true,"top|r24c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw14and15"
,"double",true,"top|r25c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 14 and 15 hour","","","","","","");
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rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw15and16"
,"double",true,"top|r26c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 015 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw16and17"
,"double",true,"top|r27c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw17and18"
,"double",true,"top|r28c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw18and19"
,"double",true,"top|r29c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw19and20"
,"double",true,"top|r30c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw20and21"
,"double",true,"top|r31c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw21and22"
,"double",true,"top|r32c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 21 and 22 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw22and23"
,"double",true,"top|r33c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterArrbtw23and24"
,"double",true,"top|r34c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeSMALLacScheduledtoDepartafterOvernight","in
t",true,"top|r35c8[ \\t=,:]","min","Standard deviation of the time SMALL ac are
scheduled to depart after arrival overnight","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw0and1",
"int",true,"top|r11c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw1and2",
"int",true,"top|r12c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw2and3",
"int",true,"top|r13c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw3and4",
"int",true,"top|r14c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 3 and 4 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw4and5",
"int",true,"top|r15c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw5and6",
"int",true,"top|r16c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw6and7",
"int",true,"top|r17c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw7and8",
"int",true,"top|r18c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 7 and 8 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw8and9",
"int",true,"top|r19c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw9and10"
,"int",true,"top|r20c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw10and11
","int",true,"top|r21c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw11and12
","int",true,"top|r22c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw12and13
","int",true,"top|r23c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
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scheduled to depart after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw13and14
","int",true,"top|r24c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw14and15
","int",true,"top|r25c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 14 and 15 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw15and16
","int",true,"top|r26c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 15 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw16and17
","int",true,"top|r27c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw17and18
","int",true,"top|r28c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw18and19
","int",true,"top|r29c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw19and20
","int",true,"top|r30c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw20and21
","int",true,"top|r31c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw21and22
","int",true,"top|r32c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 21 and 22 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw22and23
","int",true,"top|r33c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw23and24
","int",true,"top|r34c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeMEDIUMacScheduledtoDepartafterOvernight","i
nt",true,"top|r35c10[ \\t=,:]","min","Standard deviation of the time MEDIUM ac are
scheduled to depart after arrival overnight","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw0and1","
int",true,"top|r11c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw1and2","
int",true,"top|r12c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw2and3","
int",true,"top|r13c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw3and4","
int",true,"top|r14c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 3 and 4 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw4and5","
int",true,"top|r15c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw5and6","
int",true,"top|r16c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw6and7","
int",true,"top|r17c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw7and8","
int",true,"top|r18c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 7 and 8 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw8and9","
int",true,"top|r19c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw9and10",
"int",true,"top|r20c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw10and11"
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,"int",true,"top|r21c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw11and12"
,"int",true,"top|r22c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw12and13"
,"int",true,"top|r23c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw13and14"
,"int",true,"top|r24c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw14and15"
,"int",true,"top|r25c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 14 and 15 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw15and16"
,"int",true,"top|r26c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 15 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw16and17"
,"int",true,"top|r27c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw17and18"
,"int",true,"top|r28c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw18and19"
,"int",true,"top|r29c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw19and20"
,"int",true,"top|r30c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw20and21"
,"int",true,"top|r31c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw21and22"
,"int",true,"top|r32c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 21 and 22 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw22and23"
,"int",true,"top|r33c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrbtw23and24"
,"int",true,"top|r34c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeLARGEacScheduledtoDepartafterArrOvernight",
"int",true,"top|r35c12[ \\t=,:]","min","Standard deviation of the time LARGE ac are
scheduled to depart after arrival overnight","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw0and1","i
nt",true,"top|r11c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw1and2","i
nt",true,"top|r12c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw2and3","i
nt",true,"top|r13c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw3and4","i
nt",true,"top|r14c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 3 and 4 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw4and5","i
nt",true,"top|r15c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw5and6","i
nt",true,"top|r16c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw6and7","i
nt",true,"top|r17c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw7and8","i
nt",true,"top|r18c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 7 and 8 hour","","","","","","");
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rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw8and9","i
nt",true,"top|r19c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between  8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw9and10","
int",true,"top|r20c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw10and11",
"int",true,"top|r21c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw11and12",
"int",true,"top|r22c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw12and13",
"int",true,"top|r23c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw13and14",
"int",true,"top|r24c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw14and15",
"int",true,"top|r25c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 14 and 15 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw15and16",
"int",true,"top|r26c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 15 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw16and17",
"int",true,"top|r27c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw17and18",
"int",true,"top|r28c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw18and19",
"int",true,"top|r29c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw19and20",
"int",true,"top|r30c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw20and21",
"int",true,"top|r31c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw21and22",
"int",true,"top|r32c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 21 and 22 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw22and23",
"int",true,"top|r33c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrbtw23and24",
"int",true,"top|r34c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeWIDEacScheduledtoDepartafterArrOvernight","
int",true,"top|r35c14[ \\t=,:]","min","Standard deviation of the time WIDE ac are
scheduled to depart after arrival overnight","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw0and1","
int",true,"top|r11c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 0 and 1 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw1and2","
int",true,"top|r12c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 1 and 2 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw2and3","
int",true,"top|r13c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 2 and 3 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw3and4","
int",true,"top|r14c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 3 and 4 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw4and5","
int",true,"top|r15c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 4 and 5 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw5and6","
int",true,"top|r16c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
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scheduled to depart after arrival between 5 and 6 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw6and7","
int",true,"top|r17c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 6 and 7 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw7and8","
int",true,"top|r18c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 7 and 8 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw8and9","
int",true,"top|r19c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 8 and 9 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw9and10",
"int",true,"top|r20c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 9 and 10 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw10and11"
,"int",true,"top|r21c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 10 and 11 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw11and12"
,"int",true,"top|r22c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 11 and 12 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw12and13"
,"int",true,"top|r23c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 12 and 13 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw13and14"
,"int",true,"top|r24c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 13 and 14 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw14and15"
,"int",true,"top|r25c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 14 and 15 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw15and16"
,"int",true,"top|r26c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 15 and 16 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw16and17"
,"int",true,"top|r27c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 16 and 17 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw17and18"
,"int",true,"top|r28c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 17 and 18 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw18and19"
,"int",true,"top|r29c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 18 and 19 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw19and20"
,"int",true,"top|r30c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 19 and 20 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw20and21"
,"int",true,"top|r31c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 20 and 21 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw21and22"
,"int",true,"top|r32c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 21 and 22 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw22and23"
,"int",true,"top|r33c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 22 and 23 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrbtw23and24"
,"int",true,"top|r34c16[ \\t=,:]","min","Standard deviation of the time JUMBO ac are
scheduled to depart after arrival between 23 and 24 hour","","","","","","");
rowFieldInSchedule_ags.defineVar("StDevTimeJUMBOacScheduledtoDepartafterArrOvernight",
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\\t=,:]","","Fraction of domestic arrivals (between 0 and 1)","","","","","","");
rowFieldInSchedule_ags.defineVar("PercInternationalArrivals","double",true,"top|r38c2[
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rowFieldInSchedule_ags.setVariable("NbSMALLacArrivingbtw3and4","2");
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rowFieldInSchedule_ags.setVariable("NbSMALLacArrivingbtw15and16","9");
rowFieldInSchedule_ags.setVariable("NbSMALLacArrivingbtw16and17","10");
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rowFieldInSchedule_ags.setVariable("NbMEDIUMacArrivingbtw10and11","6");
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rowFieldInSchedule_ags.setVariable("NbMEDIUMacArrivingbtw18and19","9");
rowFieldInSchedule_ags.setVariable("NbMEDIUMacArrivingbtw19and20","9");
rowFieldInSchedule_ags.setVariable("NbMEDIUMacArrivingbtw20and21","7");
rowFieldInSchedule_ags.setVariable("NbMEDIUMacArrivingbtw21and22","3");
rowFieldInSchedule_ags.setVariable("NbMEDIUMacArrivingbtw22and23","2");
rowFieldInSchedule_ags.setVariable("NbMEDIUMacArrivingbtw23and24","1");
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rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw4and5","0");
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rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw8and9","5");
rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw9and10","4");
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rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw13and14","1");
rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw14and15","2");
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rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw16and17","3");
rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw17and18","4");
rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw18and19","4");
rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw19and20","4");
rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw20and21","1");
rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw21and22","1");
rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw22and23","0");
rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingbtw23and24","0");
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rowFieldInSchedule_ags.setVariable("NbLARGEacArrivingOvernight","0");
rowFieldInSchedule_ags.setVariable("NbWIDEacArrivingbtw0and1","7");
rowFieldInSchedule_ags.setVariable("NbWIDEacArrivingbtw1and2","0");
rowFieldInSchedule_ags.setVariable("NbWIDEacArrivingbtw2and3","0");
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rowFieldInSchedule_ags.setVariable("NbJUMBOacArrivingbtw0and1","0");
rowFieldInSchedule_ags.setVariable("NbJUMBOacArrivingbtw1and2","0");
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rowFieldInSchedule_ags.setVariable("AvTimeMEDIUMacScheduledtoDepartafterArrbtw22and23"
,"100");
rowFieldInSchedule_ags.setVariable("AvTimeMEDIUMacScheduledtoDepartafterArrbtw23and24"
,"100");
rowFieldInSchedule_ags.setVariable("AvTimeMEDIUMacScheduledtoDepartafterArrOvernight",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw0and1","1
20");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw1and2","1
20");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw2and3","1
20");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw3and4","1
20");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw4and5","1
20");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw5and6","1
20");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw6and7","1
20");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw7and8","1
20");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw8and9","1
20");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw9and10","
120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw10and11",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw11and12",
"120");
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"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw13and14",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw14and15",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw15and16",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw16and17",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw17and18",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw18and19",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw19and20",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw20and21",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw21and22",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw22and23",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrbtw23and24",
"120");
rowFieldInSchedule_ags.setVariable("AvTimeLARGEacScheduledtoDepartafterArrOvernight","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw0and1","0"
);
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw1and2","0"
```

```
);
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw2and3","0"
);
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw3and4","0"
);
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw4and5","0"
);
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw5and6","0"
);
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw6and7","0"
);
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw7and8","0"
);
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw8and9","0"
);
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw9and10","0
");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw10and11","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw11and12","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw12and13","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw13and14","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw14and15","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw15and16","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw16and17","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw17and18","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw18and19","
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rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw19and20","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw20and21","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw21and22","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw22and23","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrbtw23and24","
0");
rowFieldInSchedule_ags.setVariable("AvTimeWIDEacScheduledtoDepartafterArrOvernight","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw0and1","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw1and2","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw2and3","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw3and4","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw4and5","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw5and6","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw6and7","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw7and8","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw8and9","0
");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw9and10","
0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw10and11",
```

```
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw11and12",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw12and13",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw13and14",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw14and15",
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rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw15and16",
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rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw16and17",
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rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw17and18",
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rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw18and19",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw19and20",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw20and21",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw21and22",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw22and23",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrbtw23and24",
"0");
rowFieldInSchedule_ags.setVariable("AvTimeJUMBOacScheduledtoDepartafterArrOvernight","
0");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw0and1"
,"32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw1and2"
,"32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw2and3"
,"32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw3and4"
,"32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw4and5"
,"32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw5and6"
,"32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw6and7"
,"32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw7and8"
,"32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw8and9"
,"32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw9and10
","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw10and1
1","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw11and1
2","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw12and1
3","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw13and1
4","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw14and1
5","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw15and1
6","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw16and1
7","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw17and1
8","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw18and1
9","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw19and2
```

```
0","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw20and2
1","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw21and2
2","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw22and2
3","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterArrbtw23and2
4","32.5");
rowFieldInSchedule_ags.setVariable("StDevTimeSMALLacScheduledtoDepartafterOvernight","
0");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw0and1
","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw1and2
","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw2and3
","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw3and4
","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw4and5
","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw5and6
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rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw6and7
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rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw7and8
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rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw8and9
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rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw9and1
0","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw10and
11","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw11and
12","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw12and
13","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw13and
14","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw14and
15","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw15and
16","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw16and
17","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw17and
18","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw18and
19","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw19and
20","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw20and
21","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw21and
22","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw22and
23","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterArrbtw23and
24","40");
rowFieldInSchedule_ags.setVariable("StDevTimeMEDIUMacScheduledtoDepartafterOvernight",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw0and1"
,"40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw1and2"
,"40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw2and3"
,"40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw3and4"
```

```
,"40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw4and5"
,"40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw5and6"
,"40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw6and7"
,"40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw7and8"
,"40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw8and9"
,"40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw9and10
","40");
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3","40");
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5","40");
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6","40");
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7","40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw17and1
8","40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw18and1
9","40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw19and2
0","40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw20and2
1","40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw21and2
2","40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw22and2
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rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrbtw23and2
4","40");
rowFieldInSchedule_ags.setVariable("StDevTimeLARGEacScheduledtoDepartafterArrOvernight
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw0and1",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw1and2",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw2and3",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw3and4",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw4and5",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw5and6",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw6and7",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw7and8",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw8and9",
"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw9and10"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw10and11
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw11and12
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw12and13
```

```
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw13and14
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw14and15
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw15and16
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw16and17
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw17and18
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw18and19
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw19and20
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw20and21
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw21and22
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw22and23
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrbtw23and24
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeWIDEacScheduledtoDepartafterArrOvernight"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw0and1"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw1and2"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw2and3"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw3and4"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw4and5"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw5and6"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw6and7"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw7and8"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw8and9"
,"0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw9and10
","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw10and1
1","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw11and1
2","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw12and1
3","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw13and1
4","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw14and1
5","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw15and1
6","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw16and1
7","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw17and1
8","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw18and1
9","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw19and2
0","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw20and2
1","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw21and2
```

```
2","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw22and2
3","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrbtw23and2
4","0");
rowFieldInSchedule_ags.setVariable("StDevTimeJUMBOacScheduledtoDepartafterArrOvernight
","0");
rowFieldInSchedule_ags.setVariable("PercDomesticArrivals","0.8");
rowFieldInSchedule_ags.setVariable("PercInternationalArrivals","0.2");
rowFieldInSchedule_ags.readTemplate();

//File: rowFieldInRunwaySet0_rst1
//[fileDefinition="Name-Value"]
PHXRowFieldFile rowFieldInRunwaySet0_rst1 = new PHXRowFieldFile(wrapper);
rowFieldInRunwaySet0_rst1.setTemplateFile("C:\\MACAD2bis\\Input\\RunwaySet0.rst.templa
te");
rowFieldInRunwaySet0_rst1.setFileToGenerate("C:\\MACAD2bis\\Input\\RunwaySet0.rst");
rowFieldInRunwaySet0_rst1.setDelimiters(" \t=,:");



rowFieldInRunwaySet0_rst1.defineVar("RunwaySetType","int",true,"top|r1c1[
\\t=,:]","","","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACSMALLFollowSMALL","double",tru
e,"top|r4c1[ \\t=,:]","nmi","Minimum separation of approaching small ac following
small ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACSMALLFollowMEDIUM","double",tr
ue,"top|r4c2[ \\t=,:]","nmi","Minimum separation of approaching small ac following
medium ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACSMALLFollowLARGE","double",tru
e,"top|r4c3[ \\t=,:]","nmi","Minimum separation of approaching small ac following
large ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACSMALLFollowWIDE","double",true
,"top|r4c4[ \\t=,:]","nmi","Minimum separation of approaching small ac following wide
ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACSMALLFollowJUMBO","double",tru
e,"top|r4c5[ \\t=,:]","nmi","Minimum separation of approaching small ac following
jumbo ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACMEDIUMFollowSMALL","double",tr
ue,"top|r5c1[ \\t=,:]","nmi","Minimum separation of approaching medium ac following
small ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACMEDIUMFollowMEDIUM","double",t
rue,"top|r5c2[ \\t=,:]","nmi","Minimum separation of approaching medium ac following
medium ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACMEDIUMFollowLARGE","double",tr
ue,"top|r5c3[ \\t=,:]","nmi","Minimum separation of approaching medium ac following
large ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACMEDIUMFollowWIDE","double",tru
e,"top|r5c4[ \\t=,:]","nmi","Minimum separation of approaching medium ac following
wide ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACMEDIUMFollowJUMBO","double",tr
ue,"top|r5c5[ \\t=,:]","nmi","Minimum separation of approaching medium ac following
jumbo ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACLARGEFollowSMALL","double",tru
e,"top|r6c1[ \\t=,:]","nmi","Minimum separation of approaching large ac following
small ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACLARGEFollowMEDIUM","double",tr
ue,"top|r6c2[ \\t=,:]","nmi","Minimum separation of approaching large ac following
medium ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACLARGEFollowLARGE","double",tru
e,"top|r6c3[ \\t=,:]","nmi","Minimum separation of approaching large ac following
large ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACLARGEFollowWIDE","double",true
,"top|r6c4[ \\t=,:]","nmi","Minimum separation of approaching large ac following wide
ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACLARGEFollowJUMBO","double",tru
e,"top|r6c5[ \\t=,:]","nmi","Minimum separation of approaching large ac following
jumbo ac","","","","","","");
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rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACWIDEFollowSMALL","double",true
,"top|r7c1[ \\t=,:]","nmi","Minimum separation of approaching wide ac following small
ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACWIDEFollowMEDIUM","double",tru
e,"top|r7c2[ \\t=,:]","nmi","Minimum separation of approaching wide ac following
medium ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACWIDEFollowLARGE","double",true
,"top|r7c3[ \\t=,:]","nmi","Minimum separation of approaching wide ac following large
ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACWIDEFollowWIDE","double",true,
"top|r7c4[ \\t=,:]","nmi","Minimum separation of approaching wide ac following wide
ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACWIDEFollowJUMBO","double",true
,"top|r7c5[ \\t=,:]","nmi","Minimum separation of approaching wide ac following large
ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACJUMBOFollowSMALL","double",tru
e,"top|r8c1[ \\t=,:]","nmi","Minimum separation of approaching jumbo ac following
small ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACJUMBOFollowMEDIUM","double",tr
ue,"top|r8c2[ \\t=,:]","nmi","Minimum separation of approaching jumbo ac following
medium ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACJUMBOFollowLARGE","double",tru
e,"top|r8c3[ \\t=,:]","nmi","Minimum separation of approaching jumbo ac following
largel ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACJUMBOFollowWIDE","double",true
,"top|r8c4[ \\t=,:]","nmi","Minimum separation of approaching jumbo ac following wide
ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinSepApproachingACJUMBOFollowJUMBO","double",tru
e,"top|r8c5[ \\t=,:]","nmi","Minimum separation of approaching jumbo ac following
jumbo ac","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("ApproachSpeedSMALLAC","double",true,"top|r12c1[
\\t=,:]","knots","Approach speed of small aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("ApproachSpeedMEDIUMAC","double",true,"top|r12c2[
\\t=,:]","knots","Approach speed of medium aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("ApproachSpeedLARGEAC","double",true,"top|r12c3[
\\t=,:]","knots","Approach speed of large aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("ApproachSpeedWIDEAC","double",true,"top|r12c4[
\\t=,:]","knots","Approach speed of wide aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("ApproachSpeedJUMBOAC","double",true,"top|r12c5[
\\t=,:]","knots","Approach speed of jumbo aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StdDevApproachSpeedSMALLAC","double",true,"top|r1
4c1[ \\t=,:]","knots","Standard deviation of approach speed of small
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StdDevApproachSpeedMEDIUMAC","double",true,"top|r
14c2[ \\t=,:]","knots","Standard deviation of approach speed of medium
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StdDevApproachSpeedLARGEAC","double",true,"top|r1
4c3[ \\t=,:]","knots","Standard deviation of approach speed of large
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StdDevApproachSpeedWIDEAC","double",true,"top|r14
c4[ \\t=,:]","knots","Standard deviation of approach speed of wide
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StdDevApproachSpeedJUMBOAC","double",true,"top|r1
4c5[ \\t=,:]","knots","Standard deviation of approach speed of jumbo
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("PositionUncertainty","double",true,"top|r16c1[
\\t=,:]","nmi","Position uncertainty","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("LengthCommonApproachPath","double",true,"top|r18c
1[ \\t=,:]","nmi","Length of common approach path","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevWindsExpbyAC","double",true,"top|r20c1[
\\t=,:]","knots","Standard deviation of winds experienced by the
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("ArrRunwayOccTimeforSMALLac","double",true,"top|r2
2c1[ \\t=,:]","min","Arrival runway occupancy time for small
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("ArrRunwayOccTimeforMEDIUMac","double",true,"top|r
22c2[ \\t=,:]","min","Arrival runway occupancy time for medium
aircraft","","","","","","");
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rowFieldInRunwaySet0_rst1.defineVar("ArrRunwayOccTimeforLARGEac","double",true,"top|r2
2c3[ \\t=,:]","min","Arrival runway occupancy time for large
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("ArrRunwayOccTimeforWIDEac","double",true,"top|r22
c4[ \\t=,:]","min","Arrival runway occupancy time for wide
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("ArrRunwayOccTimeforJUMBOac","double",true,"top|r2
2c5[ \\t=,:]","min","Arrival runway occupancy time for jumbo
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevArrRunwayOccTimeforSMALLac","double",true,"t
op|r24c1[ \\t=,:]","min","Standard deviation of arrival runway occupancy time for
small aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevArrRunwayOccTimeforMEDIUMac","double",true,"
top|r24c2[ \\t=,:]","min","Standard deviation of arrival runway occupancy time for
medium aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevArrRunwayOccTimeforLARGEac","double",true,"t
op|r24c3[ \\t=,:]","min","Standard deviation of arrival runway occupancy time for
large aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevArrRunwayOccTimeforWIDEac","double",true,"to
p|r24c4[ \\t=,:]","min","Standard deviation of arrival runway occupancy time for wide
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevArrRunwayOccTimeforJUMBOac","double",true,"t
op|r24c5[ \\t=,:]","min","Standard deviation of arrival runway occupancy time for
large aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("DepRunwayOccTimeforSMALLac","double",true,"top|r2
6c1[ \\t=,:]","min","Departure runway occupancy time for small
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("DepRunwayOccTimeforMEDIUMac","double",true,"top|r
26c2[ \\t=,:]","min","Departure runway occupancy time for medium
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("DepRunwayOccTimeforLARGEac","double",true,"top|r2
6c3[ \\t=,:]","min","Departure runway occupancy time for large
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("DepRunwayOccTimeforWIDEac","double",true,"top|r26
c4[ \\t=,:]","min","Departure runway occupancy time for wide
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("DepRunwayOccTimeforJUMBOac","double",true,"top|r2
6c5[ \\t=,:]","min","Departure runway occupancy time for jumbo
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevDepRunwayOccTimeforSMALLac","double",true,"t
op|r28c1[ \\t=,:]","min","Standard deviation of departure runway occupancy time for
small aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevDepRunwayOccTimeforMEDIUMac","double",true,"
top|r28c2[ \\t=,:]","min","Standard deviation of departure runway occupancy time for
medium aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevDepRunwayOccTimeforLARGEac","double",true,"t
op|r28c3[ \\t=,:]","min","Standard deviation of departure runway occupancy time for
large aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevDepRunwayOccTimeforWIDEac","double",true,"to
p|r28c4[ \\t=,:]","min","Standard deviation of departure runway occupancy time for
wide aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevDepRunwayOccTimeforJUMBOac","double",true,"t
op|r28c5[ \\t=,:]","min","Standard deviation of departure runway occupancy time for
jumbo aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MeanCommTimeDelaybtwControllersandDepAC","double"
,true,"top|r30c1[ \\t=,:]","min","Mean of communication time delay between controllers
and departing aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("StDevCommTimeDelaybtwControllersandDepAC","double
",true,"top|r30c2[ \\t=,:]","min","Standard deviation of communication time delay
between controllers and departing aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinArrDepSeparation","double",true,"top|r34c1[
\\t=,:]","nmi","Minimum Arrival-Departure Separation wehn departure is about to start
to roll","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepSMALLFollowSMALL","double",true,"to
p|r36c1[ \\t=,:]","min","Minimum inter-departure separation small aircraft follow
small aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepSMALLFollowMEDIUM","double",true,"t
op|r36c2[ \\t=,:]","min","Minimum inter-departure separation small aircraft follow
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medium aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepSMALLFollowLARGE","double",true,"to
p|r36c3[ \\t=,:]","min","Minimum inter-departure separation small aircraft follow
large aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepSMALLFollowWIDE","double",true,"top
|r36c4[ \\t=,:]","min","Minimum inter-departure separation small aircraft follow wide
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepSMALLFollowJUMBO","double",true,"to
p|r36c5[ \\t=,:]","min","Minimum inter-departure separation small aircraft follow
jumbo aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepMEDIUMFollowSMALL","double",true,"t
op|r37c1[ \\t=,:]","min","Minimum inter-departure separation medium aircraft follow
small aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepMEDIUMFollowMEDIUM","double",true,"
top|r37c2[ \\t=,:]","min","Minimum inter-departure separation medium aircraft follow
medium aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepMEDIUMFollowLARGE","double",true,"t
op|r37c3[ \\t=,:]","min","Minimum inter-departure separation medium aircraft follow
large aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepMEDIUMFollowWIDE","double",true,"to
p|r37c4[ \\t=,:]","min","Minimum inter-departure separation medium aircraft follow
wide aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepMEDIUMFollowJUMBO","double",true,"t
op|r37c5[ \\t=,:]","min","Minimum inter-departure separation medium aircraft follow
jumbo aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepLARGEFollowSMALL","double",true,"to
p|r38c1[ \\t=,:]","min","Minimum inter-departure separation large aircraft follow
small aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepLARGEFollowMEDIUM","double",true,"t
op|r38c2[ \\t=,:]","min","Minimum inter-departure separation large aircraft follow
medium aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepLARGEFollowLARGE","double",true,"to
p|r38c3[ \\t=,:]","min","Minimum inter-departure separation large aircraft follow
large aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepLARGEFollowWIDE","double",true,"top
|r38c4[ \\t=,:]","min","Minimum inter-departure separation large aircraft follow wide
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepLARGEFollowJUMBO","double",true,"to
p|r38c5[ \\t=,:]","min","Minimum inter-departure separation large aircraft follow
jumbo aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepWIDEFollowSMALL","double",true,"top
|r39c1[ \\t=,:]","min","Minimum inter-departure separation wide aircraft follow small
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepWIDEFollowMEDIUM","double",true,"to
p|r39c2[ \\t=,:]","min","Minimum inter-departure separation wide aircraft follow
medium aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepWIDEFollowLARGE","double",true,"top
|r39c3[ \\t=,:]","min","Minimum inter-departure separation wide aircraft follow large
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepWIDEFollowWIDE","double",true,"top|
r39c4[ \\t=,:]","min","Minimum inter-departure separation wide aircraft follow wide
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepWIDEFollowJUMBO","double",true,"top
|r39c5[ \\t=,:]","min","Minimum inter-departure separation wide aircraft follow jumbo
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepJUMBOFollowSMALL","double",true,"to
p|r40c1[ \\t=,:]","min","Minimum inter-departure separation jumbo aircraft follow
small aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepJUMBOFollowMEDIUM","double",true,"t
op|r40c2[ \\t=,:]","min","Minimum inter-departure separation jumbo aircraft follow
medium aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepJUMBOFollowLARGE","double",true,"to
p|r40c3[ \\t=,:]","min","Minimum inter-departure separation jumbo aircraft follows
large aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepJUMBOFollowWIDE","double",true,"top
|r40c4[ \\t=,:]","min","Minimum inter-departure separation jumbo aircraft follow wide
aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.defineVar("MinInterDepSepJUMBOFollowJUMBO","double",true,"to
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p|r40c5[ \\t=,:]","min","Minimum inter-departure separation jumbo aircraft follow
jumbo aircraft","","","","","","");
rowFieldInRunwaySet0_rst1.setVariable("RunwaySetType","1");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACSMALLFollowSMALL","3.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACSMALLFollowMEDIUM","4.50");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACSMALLFollowLARGE","6.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACSMALLFollowWIDE","6.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACSMALLFollowJUMBO","6.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACMEDIUMFollowSMALL","3.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACMEDIUMFollowMEDIUM","3.50");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACMEDIUMFollowLARGE","5.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACMEDIUMFollowWIDE","5.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACMEDIUMFollowJUMBO","5.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACLARGEFollowSMALL","3.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACLARGEFollowMEDIUM","3.50");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACLARGEFollowLARGE","4.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACLARGEFollowWIDE","4.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACLARGEFollowJUMBO","4.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACWIDEFollowSMALL","3.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACWIDEFollowMEDIUM","3.50");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACWIDEFollowLARGE","4.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACWIDEFollowWIDE","4.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACWIDEFollowJUMBO","4.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACJUMBOFollowSMALL","3.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACJUMBOFollowMEDIUM","3.50");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACJUMBOFollowLARGE","4.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACJUMBOFollowWIDE","4.00");
rowFieldInRunwaySet0_rst1.setVariable("MinSepApproachingACJUMBOFollowJUMBO","4.00");
rowFieldInRunwaySet0_rst1.setVariable("ApproachSpeedSMALLAC","110.00");
rowFieldInRunwaySet0_rst1.setVariable("ApproachSpeedMEDIUMAC","135.00");
rowFieldInRunwaySet0_rst1.setVariable("ApproachSpeedLARGEAC","140.00");
rowFieldInRunwaySet0_rst1.setVariable("ApproachSpeedWIDEAC","150.00");
rowFieldInRunwaySet0_rst1.setVariable("ApproachSpeedJUMBOAC","160.00");
rowFieldInRunwaySet0_rst1.setVariable("StdDevApproachSpeedSMALLAC","5.00");
rowFieldInRunwaySet0_rst1.setVariable("StdDevApproachSpeedMEDIUMAC","5.00");
rowFieldInRunwaySet0_rst1.setVariable("StdDevApproachSpeedLARGEAC","5.00");
rowFieldInRunwaySet0_rst1.setVariable("StdDevApproachSpeedWIDEAC","5.00");
rowFieldInRunwaySet0_rst1.setVariable("StdDevApproachSpeedJUMBOAC","10.00");
rowFieldInRunwaySet0_rst1.setVariable("PositionUncertainty","0.25");
rowFieldInRunwaySet0_rst1.setVariable("LengthCommonApproachPath","6.00");
rowFieldInRunwaySet0_rst1.setVariable("StDevWindsExpbyAC","0.00");
rowFieldInRunwaySet0_rst1.setVariable("ArrRunwayOccTimeforSMALLac","0.67");
rowFieldInRunwaySet0_rst1.setVariable("ArrRunwayOccTimeforMEDIUMac","0.45");
rowFieldInRunwaySet0_rst1.setVariable("ArrRunwayOccTimeforLARGEac","0.83");
rowFieldInRunwaySet0_rst1.setVariable("ArrRunwayOccTimeforWIDEac","0.92");
rowFieldInRunwaySet0_rst1.setVariable("ArrRunwayOccTimeforJUMBOac","1.00");
rowFieldInRunwaySet0_rst1.setVariable("StDevArrRunwayOccTimeforSMALLac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("StDevArrRunwayOccTimeforMEDIUMac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("StDevArrRunwayOccTimeforLARGEac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("StDevArrRunwayOccTimeforWIDEac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("StDevArrRunwayOccTimeforJUMBOac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("DepRunwayOccTimeforSMALLac","0.83");
rowFieldInRunwaySet0_rst1.setVariable("DepRunwayOccTimeforMEDIUMac","0.92");
rowFieldInRunwaySet0_rst1.setVariable("DepRunwayOccTimeforLARGEac","1.00");
rowFieldInRunwaySet0_rst1.setVariable("DepRunwayOccTimeforWIDEac","1.08");
rowFieldInRunwaySet0_rst1.setVariable("DepRunwayOccTimeforJUMBOac","1.17");
rowFieldInRunwaySet0_rst1.setVariable("StDevDepRunwayOccTimeforSMALLac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("StDevDepRunwayOccTimeforMEDIUMac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("StDevDepRunwayOccTimeforLARGEac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("StDevDepRunwayOccTimeforWIDEac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("StDevDepRunwayOccTimeforJUMBOac","0.08");
rowFieldInRunwaySet0_rst1.setVariable("MeanCommTimeDelaybtwControllersandDepAC","0.00"
);
rowFieldInRunwaySet0_rst1.setVariable("StDevCommTimeDelaybtwControllersandDepAC","0.00
");
rowFieldInRunwaySet0_rst1.setVariable("MinArrDepSeparation","5.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepSMALLFollowSMALL","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepSMALLFollowMEDIUM","1.00");
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rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepSMALLFollowLARGE","2.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepSMALLFollowWIDE","2.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepSMALLFollowJUMBO","2.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepMEDIUMFollowSMALL","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepMEDIUMFollowMEDIUM","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepMEDIUMFollowLARGE","1.50");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepMEDIUMFollowWIDE","1.50");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepMEDIUMFollowJUMBO","1.50");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepLARGEFollowSMALL","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepLARGEFollowMEDIUM","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepLARGEFollowLARGE","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepLARGEFollowWIDE","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepLARGEFollowJUMBO","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepWIDEFollowSMALL","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepWIDEFollowMEDIUM","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepWIDEFollowLARGE","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepWIDEFollowWIDE","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepWIDEFollowJUMBO","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepJUMBOFollowSMALL","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepJUMBOFollowMEDIUM","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepJUMBOFollowLARGE","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepJUMBOFollowWIDE","1.00");
rowFieldInRunwaySet0_rst1.setVariable("MinInterDepSepJUMBOFollowJUMBO","1.00");
rowFieldInRunwaySet0_rst1.readTemplate();

//File: rowFieldInAprons_apr1
//[fileDefinition="Name-Value"]
PHXRowFieldFile rowFieldInAprons_apr1 = new PHXRowFieldFile(wrapper);
rowFieldInAprons_apr1.setTemplateFile("C:\\MACAD2bis\\Input\\Aprons.apr.template");
rowFieldInAprons_apr1.setFileToGenerate("C:\\MACAD2bis\\Input\\Aprons.apr");
rowFieldInAprons_apr1.setDelimiters(" \t=,:");



rowFieldInAprons_apr1.defineVar("StandsVacateTime","double",true,"top|r3c1[
\\t=,:]","min","Time the aircraft will vacate stands prior to their actual departure
when congestion appears for departure","","","","","","");
rowFieldInAprons_apr1.defineVar("RemoteApronPrepMeanTime","double",true,"top|r6c1[
\\t=,:]","min","Mean time required to prepare a remote apron stand after an aircraft
has been served","","","","","","");
rowFieldInAprons_apr1.defineVar("RemoteApronPrepStdDevTime","double",true,"top|r6c2[
\\t=,:]","min","Std Dev time required to prepare a remote apron stand after an
aircraft has been served","","","","","","");
rowFieldInAprons_apr1.defineVar("NoseInApronPrepMeanTime","double",true,"top|r9c1[
\\t=,:]","min","Mean time required to prepare a nose in apron stand after an aircraft
has been served","","","","","","");
rowFieldInAprons_apr1.defineVar("NoseInApronPrepStdDevTime1","double",true,"top|r9c2[
\\t=,:]","min","Std Dev time required to prepare a nose in apron stand after an
aircraft has been served","","","","","","");
rowFieldInAprons_apr1.defineVar("NbAprons","int",true,"top|r1c1[
\\t=,:]","","","","","","","","");
rowFieldInAprons_apr1.setVariable("StandsVacateTime","20.0");
rowFieldInAprons_apr1.setVariable("RemoteApronPrepMeanTime","10.0");
rowFieldInAprons_apr1.setVariable("RemoteApronPrepStdDevTime","1.0");
rowFieldInAprons_apr1.setVariable("NoseInApronPrepMeanTime","10.0");
rowFieldInAprons_apr1.setVariable("NoseInApronPrepStdDevTime1","1.0");
rowFieldInAprons_apr1.setVariable("NbAprons","23");
rowFieldInAprons_apr1.readTemplate();

//File: rowFieldOutstatistics_out
//[fileDefinition="Name-Value"]
PHXRowFieldFile rowFieldOutstatistics_out = new PHXRowFieldFile(wrapper);
rowFieldOutstatistics_out.setFileToParse("C:\\MACAD2bis\\Output\\statistics.out");
rowFieldOutstatistics_out.setDelimiters(" \t=,:");



rowFieldOutstatistics_out.defineVar("TotNbAC","int",false,"top|r12c5[
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\\t=,:]","aircraft","Total number of aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("TotArrCapacity","int",false,"top|r13c4[
\\t=,:]","aircraft?","Total Arrival Capacity","","","","","","");
rowFieldOutstatistics_out.defineVar("TotDepCapacity","int",false,"top|r14c4[
\\t=,:]","aircraft?","Total departure capacity","","","","","","");
rowFieldOutstatistics_out.defineVar("NbStands","int",false,"top|r15c4[
\\t=,:]","stands","Number of stands","","","","","","");
rowFieldOutstatistics_out.defineVar("ScheduledArrivals","int",false,"top|r17c3[
\\t=,:]","aicraft","","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelays","double",false,"top|r18c4[
\\t=,:]","min","Average arrival delays","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrivals","int",false,"top|r19c2[
\\t=,:]","aircraft","Number of Arrivals","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelay","double",false,"top|r21c4[
\\t=,:]","min","Average apron delay","","","","","","");
rowFieldOutstatistics_out.defineVar("NbAcAllocStand","int",false,"top|r22c7[
\\t=,:]","aircraft","Number of aircraft allocated a stand","","","","","","");
rowFieldOutstatistics_out.defineVar("AvNbArrforSmallAC","int",false,"top|r27c2[
\\t=,:]","aircraft","Average number of arrivals for small
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronDelayforSmallAC","double",false,"top|r27c3[
\\t=,:]","min","Apron delay for small aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvNbArrforMediumAC","int",false,"top|r28c2[
\\t=,:]","aircraft","Average number of arrivals for medium
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronDelayforMediumAC","double",false,"top|r28c3[
\\t=,:]","min","Apron delay for medium aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvNbArrforLargeAC","int",false,"top|r29c2[
\\t=,:]","aircraft","Average number of arrivals for large
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronDelayforLargeAC","double",false,"top|r29c3[
\\t=,:]","min","Apron delay for large aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvNbArrforWideAC","int",false,"top|r30c2[
\\t=,:]","aircraft","Average number of arrivals for wide aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronDelayforWideAC","double",false,"top|r30c3[
\\t=,:]","min","Apron delay for wide aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvNbArrforJumboAC","int",false,"top|r31c2[
\\t=,:]","aircraft","Average number of arrivals for jumbo
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronDelayforJumboAC","double",false,"top|r31c3[
\\t=,:]","min","Apron delay for jumbo aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvNbArrperHandler","int",false,"top|r36c2[
\\t=,:]","aircraft","Average number of arrivals for each handler","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronDelayperHandler","double",false,"top|r36c3[
\\t=,:]","min","Apron delay per handler","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDomesticArrival","int",false,"top|r38c9[
\\t=,:]","aircraft","Number of domestic arrivals","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelayforDomesticArr","double",false,"top|r
38c10[ \\t=,:]","min","Average apron delay for domestic arrivals","","","","","","");
rowFieldOutstatistics_out.defineVar("NbInternationalArrival","int",false,"top|r39c9[
\\t=,:]","aircraft","Number of international arrivals","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelayforInternationalArr","double",false,"
top|r39c10[ \\t=,:]","min","Average apron delay for international
arrivals","","","","","","");
rowFieldOutstatistics_out.defineVar("ScheduledDep","int",false,"top|r41c3[
\\t=,:]","aircraft","Scheduled departures","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelay","double",false,"top|r42c4[
\\t=,:]","min","Average departure delays","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayCongDelay","double",false,"top|r43c5[
\\t=,:]","min","Average runway congestion delay","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDep","int",false,"top|r44c2[
\\t=,:]","aircraft","Number of departures","","","","","","");
rowFieldOutstatistics_out.defineVar("AvTotalDelays","double",false,"top|r46c5[
\\t=,:]","min","Average of total delays","","","","","","");
rowFieldOutstatistics_out.defineVar("AvTotalDelayDomestic","double",false,"top|r47c5[
\\t=,:]","min","Average total delay of domestic flights","","","","","","");
rowFieldOutstatistics_out.defineVar("AvTotalDelayInternational","double",false,"top|r4
8c5[ \\t=,:]","min","Average total delay of internationa flights","","","","","","");
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rowFieldOutstatistics_out.defineVar("AvOccupancyofStands","int",false,"top|r52c5[
\\t=,:]","min","Average occupancy of stands","","","","","","");
rowFieldOutstatistics_out.defineVar("AvTimeSpentforPreparation","int",false,"top|r53c6
[ \\t=,:]","min","Average time spent for preparation","","","","","","");
rowFieldOutstatistics_out.defineVar("AvNbofACatApron","double",false,"top|r54c5[
\\t=,:]","aircraft","Average number of aircraft at aprons","","","","","","");
rowFieldOutstatistics_out.defineVar("OverallAvOccupancyTimeperHandler","double",false,
"top|r59c2[ \\t=,:]","min","Overall average occupancy time per
handler","","","","","","");
rowFieldOutstatistics_out.defineVar("NbStandsperHandler","int",false,"top|r60c1[
\\t=,:]","stands","Number of stands per handler","","","","","","");
rowFieldOutstatistics_out.defineVar("AvOccupancyperStandforeachHandler","double",false
,"top|r61c1[ \\t=,:]","min","Average occupancy per stand for each
handler","","","","","","");
rowFieldOutstatistics_out.defineVar("OverallAvOccupancyTimeperSmallAC","double",false,
"top|r67c2[ \\t=,:]","min","Overall average occupancy time per small
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("NbStandsperSmallAC","int",false,"top|r68c1[
\\t=,:]","stand","Number of stands per small aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvOccupancyperStandforSmallAC","double",false,"to
p|r69c1[ \\t=,:]","min","Average occupancy per stand for small
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("OverallAvOccupancyTimeperMediumAC","double",false
,"top|r70c2[ \\t=,:]","min","Overall average occupancy time per medium
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("NbStandsperMediumAC","int",false,"top|r71c1[
\\t=,:]","stand","Number of stands per medium aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvOccupancyperStandforMediumAC","double",false,"t
op|r72c1[ \\t=,:]","min","Average occupancy per stand for medium
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("OverallAvOccupancyTimeperLargeAC","double",false,
"top|r73c2[ \\t=,:]","min","Overall average occupancy time per large
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("NbStandsperLargeAC","int",false,"top|r74c1[
\\t=,:]","stand","Number of stands per large aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvOccupancyperStandforLargeAC","double",false,"to
p|r75c1[ \\t=,:]","min","Average occupancy per stand for large
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("OveralAvOccupancyTimeperWideAC","double",false,"t
op|r76c2[ \\t=,:]","min","Overall average occupancy time per wide
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("NbStandsperWideAC","int",false,"top|r77c1[
\\t=,:]","stand","Number of stands per wide aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvOccupancyperStandforWideAC","double",false,"top
|r78c1[ \\t=,:]","min","Average occupancy per stand for wide
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("OverallAvOccupancyTimeperJumboAC","double",false,
"top|r79c2[ \\t=,:]","min","Overall average occupancy time per jumbo
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("NbStandsperJumboAC","int",false,"top|r80c1[
\\t=,:]","stand","Number of stands per jumbo aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvOccupancyperStandforJumboAC","double",false,"to
p|r81c1[ \\t=,:]","min","Average occupancy per stand for jumbo
aircraft","","","","","","");
rowFieldOutstatistics_out.defineVar("AvOccupancyofDomesticFlights","int",false,"top|r8
3c6[ \\t=,:]","min","Average occupancy of domestic flights","","","","","","");
rowFieldOutstatistics_out.defineVar("AvOccupancyofInternationalFlights","int",false,"t
op|r84c6[ \\t=,:]","min","Average occupancy of domestic flights","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDelayStandDepduetoDepRunCongestion","int",false
,"top|r87c4[ \\t=,:]","min","average delay in stand departure due to departure run
congestion","","","","","","");
rowFieldOutstatistics_out.defineVar("TotalTimeApronBufferFull","int",false,"top|r88c8[
\\t=,:]","min","Total time the apron buffer was full","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentArrDelayedbtw0and5min","double",false,"top
|r91c10[ \\t=,:]","percent","Percentage of arrivals delayed between 0 and 5
min","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentArrDelayedbtw5and15min","double",false,"to
p|r92c10[ \\t=,:]","percent","Percentage of arrivals delayed between 5 and 15
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min","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentArrDelayedbtw15and30min","double",false,"t
op|r93c10[ \\t=,:]","percent","Percentage of arrivals delayed between 15 and 30
min","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentArrDelayedmorethan30min","double",false,"t
op|r94c9[ \\t=,:]","percent","Percentage of arrivals delayed more than 30
min","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentDepDelayedbtw0and5min","double",false,"top
|r96c10[ \\t=,:]","percent","Percentage of departures delayed between 0 and 5
min","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentDepDelayedbtw5and15min","double",false,"to
p|r97c10[ \\t=,:]","percent","Percentage of departures delayed between 5 and 15
min","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentDepDelayedbtw15and30min","double",false,"t
op|r98c10[ \\t=,:]","percent","Percentage of departures delayed between 15 and 30
min","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentDepDelayedmorethan30min","double",false,"t
op|r99c9[ \\t=,:]","percent","Percentage of departures delayed more than 30
min","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentDepDelayedduetoRunwayCongestionbtw0and5min
","double",false,"top|r101c14[ \\t=,:]","percent","Percentage of departures delayed
due to runway congestion between 0 and 5 mins","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentDepDelayedduetoRunwayCongestionbtw5and15mi
n","double",false,"top|r102c14[ \\t=,:]","percent","Percentage of departures delayed
due to runway congestion between 5 and 15 mins","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentDepDelayedduetoRunwayCongestionbtw15and30m
in","double",false,"top|r103c14[ \\t=,:]","percent","Percentage of departures delayed
due to runway congestion between 15 and 30 mins","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentDepDelayedduetoRunwayCongestionmorethan30m
in","double",false,"top|r104c9[ \\t=,:]","percent","Percentage of departures delayed
due to runway congestion more than 30 mins","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentACDelayedinApronbtw0and5min","double",fals
e,"top|r106c13[ \\t=,:]","percent","Percentage of aircraft delayed in the apron
between 0 and 5 mins","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentACDelayedinApronbtw5and15min","double",fal
se,"top|r107c13[ \\t=,:]","percent","Percentage of aircraft delayed in the apron
between 5 and 15 mins","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentACDelayedinApronbtw15and30min","double",fa
lse,"top|r108c13[ \\t=,:]","percent","Percentage of aircraft delayed in the apron
between 15 and 30 mins","","","","","","");
rowFieldOutstatistics_out.defineVar("PercentACDelayedinApronmorethan30min","double",fa
lse,"top|r109c12[ \\t=,:]","percent","Percentage of aircraft delayed in the apronmore
than 30 mins","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour0andHour1","double",false,"
top|r114c4[ \\t=,:]","min","Average arrival delays between hour 0 and hour
1","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour1andHour2","double",false,"
top|r114c5[ \\t=,:]","min","Average arrival delays between hour 1 and hour
2","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour2andHour3","double",false,"
top|r114c6[ \\t=,:]","min","Average arrival delays between hour 2 and hour
3","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour3andHour4","double",false,"
top|r114c7[ \\t=,:]","min","Average arrival delays between hour 3 and hour
4","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour4andHour5","double",false,"
top|r114c8[ \\t=,:]","min","Average arrival delays between hour 4 and hour
5","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour5andHour6","double",false,"
top|r114c9[ \\t=,:]","min","Average arrival delays between hour 5 and hour
6","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour6andHour7","double",false,"
top|r114c10[ \\t=,:]","min","Average arrival delays between hour 6 and hour
7","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour7andHour8","double",false,"
top|r114c11[ \\t=,:]","min","Average arrival delays between hour 7 and hour
8","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour8andHour9","double",false,"
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top|r114c12[ \\t=,:]","min","Average arrival delays between hour 8 and hour
9","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour9andHour10","double",false,
"top|r114c13[ \\t=,:]","min","Average arrival delays between hour 9 and hour
10","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour10andHour11","double",false
,"top|r114c14[ \\t=,:]","min","Average arrival delays between hour 10 and hour
11","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour11andHour12","double",false
,"top|r114c15[ \\t=,:]","min","Average arrival delays between hour 11 and hour
12","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour12andHour13","double",false
,"top|r114c16[ \\t=,:]","min","Average arrival delays between hour 12 and hour
13","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour13andHour14","double",false
,"top|r114c17[ \\t=,:]","min","Average arrival delays between hour 13 and hour
14","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour14andHour15","double",false
,"top|r114c18[ \\t=,:]","min","Average arrival delays between hour 14 and hour
15","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour15andHour16","double",false
,"top|r114c19[ \\t=,:]","min","Average arrival delays between hour 15 and hour
16","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour16andHour17","double",false
,"top|r114c20[ \\t=,:]","min","Average arrival delays between hour 16 and hour
17","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour17andHour18","double",false
,"top|r114c21[ \\t=,:]","min","Average arrival delays between hour 17 and hour
18","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour18andHour19","double",false
,"top|r114c22[ \\t=,:]","min","Average arrival delays between hour 18 and hour
19","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour19andHour20","double",false
,"top|r114c23[ \\t=,:]","min","Average arrival delays between hour 19 and hour
20","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour20andHour21","double",false
,"top|r114c24[ \\t=,:]","min","Average arrival delays between hour 20 and hour
21","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour21andHour22","double",false
,"top|r114c25[ \\t=,:]","min","Average arrival delays between hour 21 and hour
22","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour22andHour23","double",false
,"top|r114c26[ \\t=,:]","min","Average arrival delays between hour 22 and hour
23","","","","","","");
rowFieldOutstatistics_out.defineVar("AvArrDelaysbetweenHour23andHour24","double",false
,"top|r114c27[ \\t=,:]","min","Average arrival delays between hour 23 and hour
24","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour0andHour1","int",false,"top|r115c4[
\\t=,:]","aircraft","Number of arrivals between hour 0 and hour 1","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour1andHour2","int",false,"top|r115c5[
\\t=,:]","aircraft","Number of arrivals between hour 1 and hour 2","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour2andHour3","int",false,"top|r115c6[
\\t=,:]","aircraft","Number of arrivals between hour 2 and hour 3","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour3andHour4","int",false,"top|r115c7[
\\t=,:]","aircraft","Number of arrivals between hour 3 and hour 4","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour4andHour5","int",false,"top|r115c8[
\\t=,:]","aircraft","Number of arrivals between hour 4 and hour 5","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour5andHour6","int",false,"top|r115c9[
\\t=,:]","aircraft","Number of arrivals between hour 5 and hour 6","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour6andHour7","int",false,"top|r115c10[
\\t=,:]","aircraft","Number of arrivals between hour 6 and hour 7","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour7andHour8","int",false,"top|r115c11[
\\t=,:]","aircraft","Number of arrivals between hour 7 and hour 8","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour8andHour9","int",false,"top|r115c12[
\\t=,:]","aircraft","Number of arrivals between hour 8 and hour 9","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour9andHour10","int",false,"top|r115c13[
\\t=,:]","aircraft","Number of arrivals between hour 9 and hour
10","","","","","","");
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rowFieldOutstatistics_out.defineVar("NbArrbtwHour10andHour11","int",false,"top|r115c14
[ \\t=,:]","aircraft","Number of arrivals between hour 10 and hour
11","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour11andHour12","int",false,"top|r115c15
[ \\t=,:]","aircraft","Number of arrivals between hour 11 and hour
12","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour12andHour13","int",false,"top|r115c16
[ \\t=,:]","aircraft","Number of arrivals between hour 12 and hour
13","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour13andHour14","int",false,"top|r115c17
[ \\t=,:]","aircraft","Number of arrivals between hour 13 and hour
14","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour14andHour15","int",false,"top|r115c18
[ \\t=,:]","aircraft","Number of arrivals between hour 14 and hour
15","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour15andHour16","int",false,"top|r115c19
[ \\t=,:]","aircraft","Number of arrivals between hour 15 and hour
16","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour16andHour17","int",false,"top|r115c20
[ \\t=,:]","aircraft","Number of arrivals between hour 16 and hour
17","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour17andHour18","int",false,"top|r115c21
[ \\t=,:]","aircraft","Number of arrivals between hour 17 and hour
18","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour18andHour19","int",false,"top|r115c22
[ \\t=,:]","aircraft","Number of arrivals between hour 18 and hour
19","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour19andHour20","int",false,"top|r115c23
[ \\t=,:]","aircraft","Number of arrivals between hour 19 and hour
20","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour20andHour21","int",false,"top|r115c24
[ \\t=,:]","aircraft","Number of arrivals between hour 20 and hour
21","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour21andHour22","int",false,"top|r115c25
[ \\t=,:]","aircraft","Number of arrivals between hour 21 and hour
22","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour22andHour23","int",false,"top|r115c26
[ \\t=,:]","aircraft","Number of arrivals between hour 22 and hour
23","","","","","","");
rowFieldOutstatistics_out.defineVar("NbArrbtwHour23andHour24","int",false,"top|r115c27
[ \\t=,:]","aircraft","Number of arrivals between hour 23 and hour
24","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour0andHour1","double",false,"
top|r121c4[ \\t=,:]","min","Average departure delays between hour 0 and hour
1","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour1andHour2","double",false,"
top|r121c5[ \\t=,:]","min","Average departure delays between hour 1 and hour
2","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour2andHour3","double",false,"
top|r121c6[ \\t=,:]","min","Average departure delays between hour 2 and hour
3","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour3andHour4","double",false,"
top|r121c7[ \\t=,:]","min","Average departure delays between hour 3 and hour
4","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour4andHour5","double",false,"
top|r121c8[ \\t=,:]","min","Average departure delays between hour 4 and hour
5","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour5andHour6","double",false,"
top|r121c9[ \\t=,:]","min","Average departure delays between hour 5 and hour
6","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour6andHour7","double",false,"
top|r121c10[ \\t=,:]","min","Average departure delays between hour 6 and hour
7","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour7andHour8","double",false,"
top|r121c11[ \\t=,:]","min","Average departure delays between hour 7 and hour
8","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour8andHour9","double",false,"
top|r121c12[ \\t=,:]","min","Average departure delays between hour 8 and hour
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9","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour9andHour10","double",false,
"top|r121c13[ \\t=,:]","min","Average departure delays between hour 9 and hour
10","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour10andHour11","double",false
,"top|r121c14[ \\t=,:]","min","Average departure delays between hour 10 and hour
11","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour11andHour12","double",false
,"top|r121c15[ \\t=,:]","min","Average departure delays between hour 11 and hour
12","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour12andHour13","double",false
,"top|r121c16[ \\t=,:]","min","Average departure delays between hour 12 and hour
13","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour13andHour14","double",false
,"top|r121c17[ \\t=,:]","min","Average departure delays between hour 13 and hour
14","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour14andHour15","double",false
,"top|r121c18[ \\t=,:]","min","Average departure delays between hour 14 and hour
15","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour15andHour16","double",false
,"top|r121c19[ \\t=,:]","min","Average departure delays between hour 15 and hour
16","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour16andHour17","double",false
,"top|r121c20[ \\t=,:]","min","Average departure delays between hour 16 and hour
17","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour17andHour18","double",false
,"top|r121c21[ \\t=,:]","min","Average departure delays between hour 17 and hour
18","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour18andHour19","double",false
,"top|r121c22[ \\t=,:]","min","Average departure delays between hour 18 and hour
19","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour19andHour20","double",false
,"top|r121c23[ \\t=,:]","min","Average departure delays between hour 19 and hour
20","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour20andHour21","double",false
,"top|r121c24[ \\t=,:]","min","Average departure delays between hour 20 and hour
21","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour21andHour22","double",false
,"top|r121c25[ \\t=,:]","min","Average departure delays between hour 21 and hour
22","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour22andHour23","double",false
,"top|r121c26[ \\t=,:]","min","Average departure delays between hour 22 and hour
23","","","","","","");
rowFieldOutstatistics_out.defineVar("AvDepDelaysbetweenHour23andHour24","double",false
,"top|r121c27[ \\t=,:]","min","Average departure delays between hour 23 and hour
24","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour0andHour1","int",false,"top|r122c4[
\\t=,:]","aircraft","Number of departures between hour 0 and hour
1","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour1andHour2","int",false,"top|r122c5[
\\t=,:]","aircraft","Number of departures between hour 1 and hour
2","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour2andHour3","int",false,"top|r122c6[
\\t=,:]","aircraft","Number of departures between hour 2 and hour
3","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour3andHour4","int",false,"top|r122c7[
\\t=,:]","aircraft","Number of departures between hour 3 and hour
4","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour4andHour5","int",false,"top|r122c8[
\\t=,:]","aircraft","Number of departures between hour 4 and hour
5","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour5andHour6","int",false,"top|r122c9[
\\t=,:]","aircraft","Number of departures between hour 5 and hour
6","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour6andHour7","int",false,"top|r122c10[
\\t=,:]","aircraft","Number of departures between hour 6 and hour
7","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour7andHour8","int",false,"top|r122c11[
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\\t=,:]","aircraft","Number of departures between hour 7 and hour
8","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour8andHour9","int",false,"top|r122c12[
\\t=,:]","aircraft","Number of departures between hour 8 and hour
9","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour9andHour10","int",false,"top|r122c13[
\\t=,:]","aircraft","Number of departures between hour 9 and hour
10","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour10andHour11","int",false,"top|r122c14
[ \\t=,:]","aircraft","Number of departures between hour 10 and hour
11","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour11andHour12","int",false,"top|r122c15
[ \\t=,:]","aircraft","Number of departures between hour 11 and hour
12","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour12andHour13","int",false,"top|r122c16
[ \\t=,:]","aircraft","Number of departures between hour 12 and hour
13","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour13andHour14","int",false,"top|r122c17
[ \\t=,:]","aircraft","Number of departures between hour 13 and hour
14","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour14andHour15","int",false,"top|r122c18
[ \\t=,:]","aircraft","Number of departures between hour 14 and hour
15","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour15andHour16","int",false,"top|r122c19
[ \\t=,:]","aircraft","Number of departures between hour 15 and hour
16","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour16andHour17","int",false,"top|r122c20
[ \\t=,:]","aircraft","Number of departures between hour 16 and hour
17","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour17andHour18","int",false,"top|r122c21
[ \\t=,:]","aircraft","Number of departures between hour 17 and hour
18","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour18andHour19","int",false,"top|r122c22
[ \\t=,:]","aircraft","Number of departures between hour 18 and hour
19","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour19andHour20","int",false,"top|r122c23
[ \\t=,:]","aircraft","Number of departures between hour 19 and hour
20","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour20andHour21","int",false,"top|r122c24
[ \\t=,:]","aircraft","Number of departures between hour 20 and hour
21","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour21andHour22","int",false,"top|r122c25
[ \\t=,:]","aircraft","Number of departures between hour 21 and hour
22","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour22andHour23","int",false,"top|r122c26
[ \\t=,:]","aircraft","Number of departures between hour 22 and hour
23","","","","","","");
rowFieldOutstatistics_out.defineVar("NbDepbtwHour23andHour24","int",false,"top|r122c27
[ \\t=,:]","aircraft","Number of departures between hour 23 and hour
24","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour0andHour1","int",false,"top|r13
1c5[ \\t=,:]","aircraft","Actual number of departures between hour 0 and hour
1","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour1andHour2","int",false,"top|r13
1c6[ \\t=,:]","aircraft","Actual number of departures between hour 1 and hour
2","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour2andHour3","int",false,"top|r13
1c7[ \\t=,:]","aircraft","Actual number of departures between hour 2 and hour
3","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour3andHour4","int",false,"top|r13
1c8[ \\t=,:]","aircraft","Actual number of departures between hour 3 and hour
4","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour4andHour5","int",false,"top|r13
1c9[ \\t=,:]","aircraft","Actual number of departures between hour 4 and hour
5","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour5andHour6","int",false,"top|r13
1c10[ \\t=,:]","aircraft","Actual number of departures between hour 5 and hour
6","","","","","","");
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rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour6andHour7","int",false,"top|r13
1c11[ \\t=,:]","aircraft","Actual number of departures between hour 6 and hour
7","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour7andHour8","int",false,"top|r13
1c12[ \\t=,:]","aircraft","Actual number of departures between hour 7 and hour
8","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour8andHour9","int",false,"top|r13
1c13[ \\t=,:]","aircraft","Actual number of departures between hour 8 and hour
9","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour9andHour10","int",false,"top|r1
31c14[ \\t=,:]","aircraft","Actual number of departures between hour 9 and hour
10","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour10andHour11","int",false,"top|r
131c15[ \\t=,:]","aircraft","Actual number of departures between hour 10 and hour
11","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour11andHour12","int",false,"top|r
131c16[ \\t=,:]","aircraft","Actual number of departures between hour 11 and hour
12","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour12andHour13","int",false,"top|r
131c17[ \\t=,:]","aircraft","Actual number of departures between hour 12 and hour
13","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour13andHour14","int",false,"top|r
131c18[ \\t=,:]","aircraft","Actual number of departures between hour 13 and hour
14","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour14andHour15","int",false,"top|r
131c19[ \\t=,:]","aircraft","Actual number of departures between hour 14 and hour
15","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour15andHour16","int",false,"top|r
131c20[ \\t=,:]","aircraft","Actual number of departures between hour 15 and hour
16","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour16andHour17","int",false,"top|r
131c21[ \\t=,:]","aircraft","Actual number of departures between hour 16 and hour
17","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour17andHour18","int",false,"top|r
131c22[ \\t=,:]","aircraft","Actual number of departures between hour 17 and hour
18","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour18andHour19","int",false,"top|r
131c23[ \\t=,:]","aircraft","Actual number of departures between hour 18 and hour
19","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour19andHour20","int",false,"top|r
131c24[ \\t=,:]","aircraft","Actual number of departures between hour 19 and hour
20","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour20andHour21","int",false,"top|r
131c25[ \\t=,:]","aircraft","Actual number of departures between hour 20 and hour
21","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour21andHour22","int",false,"top|r
131c26[ \\t=,:]","aircraft","Actual number of departures between hour 21 and hour
22","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour22andHour23","int",false,"top|r
131c27[ \\t=,:]","aircraft","Actual number of departures between hour 22 and hour
23","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbDepbtwHour23andHour24","int",false,"top|r
131c28[ \\t=,:]","aircraft","Actual number of departures between hour 23 and hour
24","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour0andHour1","double",false,
"top|r133c5[ \\t=,:]","min","Average runway departure delay between hour 0 and hour
1","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour1andHour2","double",false,
"top|r133c6[ \\t=,:]","min","Average runway departure delay between hour 1 and hour
2","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour2andHour3","double",false,
"top|r133c7[ \\t=,:]","min","Average runway departure delay between hour 2 and hour
3","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour3andHour4","double",false,
"top|r133c8[ \\t=,:]","min","Average runway departure delay between hour 3 and hour
4","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour4andHour5","double",false,
"top|r133c9[ \\t=,:]","min","Average runway departure delay between hour 4 and hour
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5","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour5andHour6","double",false,
"top|r133c10[ \\t=,:]","min","Average runway departure delay between hour 5 and hour
6","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour6andHour7","double",false,
"top|r133c11[ \\t=,:]","min","Average runway departure delay between hour 6 and hour
7","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour7andHour8","double",false,
"top|r133c12[ \\t=,:]","min","Average runway departure delay between hour 7 and hour
8","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour8andHour9","double",false,
"top|r133c13[ \\t=,:]","min","Average runway departure delay between hour 8 and hour
9","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour9andHour10","double",false
,"top|r133c14[ \\t=,:]","min","Average runway departure delay between hour 9 and hour
10","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour10andHour11","double",fals
e,"top|r133c15[ \\t=,:]","min","Average runway departure delay between hour 10 and
hour 11","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour11andHour12","double",fals
e,"top|r133c16[ \\t=,:]","min","Average runway departure delay between hour 11 and
hour 12","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour12andHour13","double",fals
e,"top|r133c17[ \\t=,:]","min","Average runway departure delay between hour 12 and
hour 13","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour13andHour14","double",fals
e,"top|r133c18[ \\t=,:]","min","Average runway departure delay between hour 13 and
hour 14","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour14andHour15","double",fals
e,"top|r133c19[ \\t=,:]","min","Average runway departure delay between hour 14 and
hour 15","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour15andHour16","double",fals
e,"top|r133c20[ \\t=,:]","min","Average runway departure delay between hour 15 and
hour 16","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour16andHour17","double",fals
e,"top|r133c21[ \\t=,:]","min","Average runway departure delay between hour 16 and
hour 17","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour17andHour18","double",fals
e,"top|r133c22[ \\t=,:]","min","Average runway departure delay between hour 17 and
hour 18","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour18andHour19","double",fals
e,"top|r133c23[ \\t=,:]","min","Average runway departure delay between hour 18 and
hour 19","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour19andHour20","double",fals
e,"top|r133c24[ \\t=,:]","min","Average runway departure delay between hour 19 and
hour 20","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour20andHour21","double",fals
e,"top|r133c25[ \\t=,:]","min","Average runway departure delay between hour 20 and
hour 21","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour21andHour22","double",fals
e,"top|r133c26[ \\t=,:]","min","Average runway departure delay between hour 21 and
hour 22","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour22andHour23","double",fals
e,"top|r133c27[ \\t=,:]","min","Average runway departure delay between hour 22 and
hour 23","","","","","","");
rowFieldOutstatistics_out.defineVar("AvRunwayDepDelaybtwHour23andHour24","double",fals
e,"top|r133c28[ \\t=,:]","min","Average runway departure delay between hour 23 and
hour 24","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour0andHour1","double",false,"top
|r139c4[ \\t=,:]","min","Average apron delay between hour 0 and hour
1","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour1andHour2","double",false,"top
|r139c5[ \\t=,:]","min","Average apron delay between hour 1 and hour
2","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour2andHour3","double",false,"top
|r139c6[ \\t=,:]","min","Average apron delay between hour 2 and hour
3","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour3andHour4","double",false,"top
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|r139c7[ \\t=,:]","min","Average apron delay between hour 3 and hour
4","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour4andHour5","double",false,"top
|r139c8[ \\t=,:]","min","Average apron delay between hour 4 and hour
5","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour5andHour6","double",false,"top
|r139c9[ \\t=,:]","min","Average apron delay between hour 5 and hour
6","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour6andHour7","double",false,"top
|r139c10[ \\t=,:]","min","Average apron delay between hour 6 and hour
7","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour7andHour8","double",false,"top
|r139c11[ \\t=,:]","min","Average apron delay between hour 7 and hour
8","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour8andHour9","double",false,"top
|r139c12[ \\t=,:]","min","Average apron delay between hour 8 and hour
9","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour9andHour10","double",false,"to
p|r139c13[ \\t=,:]","min","Average apron delay between hour 9 and hour
10","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour10andHour11","double",false,"t
op|r139c14[ \\t=,:]","min","Average apron delay between hour 10 and hour
11","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour11andHour12","double",false,"t
op|r139c15[ \\t=,:]","min","Average apron delay between hour 11 and hour
12","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour12andHour13","double",false,"t
op|r139c16[ \\t=,:]","min","Average apron delay between hour 12 and hour
13","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour13andHour14","double",false,"t
op|r139c17[ \\t=,:]","min","Average apron delay between hour 13 and hour
14","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour14andHour15","double",false,"t
op|r139c18[ \\t=,:]","min","Average apron delay between hour 14 and hour
15","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour15andHour16","double",false,"t
op|r139c19[ \\t=,:]","min","Average apron delay between hour 15 and hour
16","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour16andHour17","double",false,"t
op|r139c20[ \\t=,:]","min","Average apron delay between hour 16 and hour
17","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour17andHour18","double",false,"t
op|r139c21[ \\t=,:]","min","Average apron delay between hour 17 and hour
18","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour18andHour19","double",false,"t
op|r139c22[ \\t=,:]","min","Average apron delay between hour 18 and hour
19","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour19andHour20","double",false,"t
op|r139c23[ \\t=,:]","min","Average apron delay between hour 19 and hour
20","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour20andHour21","double",false,"t
op|r139c24[ \\t=,:]","min","Average apron delay between hour 20 and hour
21","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour21andHour22","double",false,"t
op|r139c25[ \\t=,:]","min","Average apron delay between hour 21 and hour
22","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour22andHour23","double",false,"t
op|r139c26[ \\t=,:]","min","Average apron delay between hour 22 and hour
23","","","","","","");
rowFieldOutstatistics_out.defineVar("AvApronDelaybtwHour23andHour24","double",false,"t
op|r139c27[ \\t=,:]","min","Average apron delay between hour 23 and hour
24","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour0andHour1","int",false,"top|r14
0c5[ \\t=,:]","aircraft","Actual number of arrivals between hour 0 and hour
1","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour1andHour2","int",false,"top|r14
0c6[ \\t=,:]","aircraft","Actual number of arrivals between hour 1 and hour
2","","","","","","");
```

```
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour2andHour3","int",false,"top|r14
0c7[ \\t=,:]","aircraft","Actual number of arrivals between hour 2 and hour
3","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour3andHour4","int",false,"top|r14
0c8[ \\t=,:]","aircraft","Actual number of arrivals between hour 3 and hour
4","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour4andHour5","int",false,"top|r14
0c9[ \\t=,:]","aircraft","Actual number of arrivals between hour 4 and hour
5","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour5andHour6","int",false,"top|r14
0c10[ \\t=,:]","aircraft","Actual number of arrivals between hour 5 and hour
6","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour6andHour7","int",false,"top|r14
0c11[ \\t=,:]","aircraft","Actual number of arrivals between hour 6 and hour
7","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour7andHour8","int",false,"top|r14
0c12[ \\t=,:]","aircraft","Actual number of arrivals between hour 7 and hour
8","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour8andHour9","int",false,"top|r14
0c13[ \\t=,:]","aircraft","Actual number of arrivals between hour 8 and hour
9","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour9andHour10","int",false,"top|r1
40c14[ \\t=,:]","aircraft","Actual number of arrivals between hour 9 and hour
10","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour10andHour11","int",false,"top|r
140c15[ \\t=,:]","aircraft","Actual number of arrivals between hour 10 and hour
11","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour11andHour12","int",false,"top|r
140c16[ \\t=,:]","aircraft","Actual number of arrivals between hour 11 and hour
12","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour12andHour13","int",false,"top|r
140c17[ \\t=,:]","aircraft","Actual number of arrivals between hour 12 and hour
13","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour13andHour14","int",false,"top|r
140c18[ \\t=,:]","aircraft","Actual number of arrivals between hour 13 and hour
14","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour14andHour15","int",false,"top|r
140c19[ \\t=,:]","aircraft","Actual number of arrivals between hour 14 and hour
15","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour15andHour16","int",false,"top|r
140c20[ \\t=,:]","aircraft","Actual number of arrivals between hour 15 and hour
16","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour16andHour17","int",false,"top|r
140c21[ \\t=,:]","aircraft","Actual number of arrivals between hour 16 and hour
17","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour17andHour18","int",false,"top|r
140c22[ \\t=,:]","aircraft","Actual number of arrivals between hour 17 and hour
18","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour18andHour19","int",false,"top|r
140c23[ \\t=,:]","aircraft","Actual number of arrivals between hour 18 and hour
19","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour19andHour20","int",false,"top|r
140c24[ \\t=,:]","aircraft","Actual number of arrivals between hour 19 and hour
20","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour20andHour21","int",false,"top|r
140c25[ \\t=,:]","aircraft","Actual number of arrivals between hour 20 and hour
21","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour21andHour22","int",false,"top|r
140c26[ \\t=,:]","aircraft","Actual number of arrivals between hour 21 and hour
22","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour22andHour23","int",false,"top|r
140c27[ \\t=,:]","aircraft","Actual number of arrivals between hour 22 and hour
23","","","","","","");
rowFieldOutstatistics_out.defineVar("ActualNbArrbtwHour23andHour24","int",false,"top|r
140c28[ \\t=,:]","aircraft","Actual number of arrivals between hour 23 and hour
24","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour0andHour1","double",false,"
top|r147c4[ \\t=,:]","min","Apron buffer full between hour 0 and hour
```

```
1","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour1andHour2","double",false,"
top|r147c5[ \\t=,:]","min","Apron buffer full between hour 1 and hour
2","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour2andHour3","double",false,"
top|r147c6[ \\t=,:]","min","Apron buffer full between hour 2 and hour
3","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour3andHour4","double",false,"
top|r147c7[ \\t=,:]","min","Apron buffer full between hour 3 and hour
4","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour4andHour5","double",false,"
top|r147c8[ \\t=,:]","min","Apron buffer full between hour 4 and hour
5","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour5andHour6","double",false,"
top|r147c9[ \\t=,:]","min","Apron buffer full between hour 5 and hour
6","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour6andHour7","double",false,"
top|r147c10[ \\t=,:]","min","Apron buffer full between hour 6 and hour
7","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour7andHour8","double",false,"
top|r147c11[ \\t=,:]","min","Apron buffer full between hour 7 and hour
8","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour8andHour9","double",false,"
top|r147c12[ \\t=,:]","min","Apron buffer full between hour 8 and hour
9","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour9andHour10","double",false,
"top|r147c13[ \\t=,:]","min","Apron buffer full between hour 9 and hour
10","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour10andHour11","double",false
,"top|r147c14[ \\t=,:]","min","Apron buffer full between hour 10 and hour
11","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour11andHour12","double",false
,"top|r147c15[ \\t=,:]","min","Apron buffer full between hour 11 and hour
12","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour12andHour13","double",false
,"top|r147c16[ \\t=,:]","min","Apron buffer full between hour 12 and hour
13","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour13andHour14","double",false
,"top|r147c17[ \\t=,:]","min","Apron buffer full between hour 13 and hour
14","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour14andHour15","double",false
,"top|r147c18[ \\t=,:]","min","Apron buffer full between hour 14 and hour
15","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour15andHour16","double",false
,"top|r147c19[ \\t=,:]","min","Apron buffer full between hour 15 and hour
16","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour16andHour17","double",false
,"top|r147c20[ \\t=,:]","min","Apron buffer full between hour 16 and hour
17","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour17andHour18","double",false
,"top|r147c21[ \\t=,:]","min","Apron buffer full between hour 17 and hour
18","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour18andHour19","double",false
,"top|r147c22[ \\t=,:]","min","Apron buffer full between hour 18 and hour
19","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour19andHour20","double",false
,"top|r147c23[ \\t=,:]","min","Apron buffer full between hour 19 and hour
20","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour20andHour21","double",false
,"top|r147c24[ \\t=,:]","min","Apron buffer full between hour 20 and hour
21","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour21andHour22","double",false
,"top|r147c25[ \\t=,:]","min","Apron buffer full between hour 21 and hour
22","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour22andHour23","double",false
,"top|r147c26[ \\t=,:]","min","Apron buffer full between hour 22 and hour
23","","","","","","");
rowFieldOutstatistics_out.defineVar("ApronBufferFullbtwHour23andHour24","double",false
```

```
,"top|r147c27[ \\t=,:]","min","Apron buffer full between hour 23 and hour
24","","","","","","");
try
{
   rowFieldOutstatistics_out.readTemplate();
}
catch ( Exception )
{
   // the output file didn't exist
}

//File: rowFieldOutRunSets_rso
//[fileDefinition="Name-Value"]
PHXRowFieldFile rowFieldOutRunSets_rso = new PHXRowFieldFile(wrapper);
rowFieldOutRunSets_rso.setFileToParse("C:\\MACAD2bis\\Output\\RunSets.rso");
rowFieldOutRunSets_rso.setDelimiters(" \t=,:");



rowFieldOutRunSets_rso.defineVar("ArrivalCapacityperHourEvenMix","double",false,"top|r
6c1[ \\t=,:]","","","","","","","","");
rowFieldOutRunSets_rso.defineVar("DepartureCapacityperHourEvenMix","double",false,"top
|r6c2[ \\t=,:]","","","","","","","","");
try
{
   rowFieldOutRunSets_rso.readTemplate();
}
catch ( Exception )
{
   // the output file didn't exist
}

//exceptions not thrown (SEE parseFile() documentation)

void generate()
{
   rowFieldInMaster_in.generate();
   rowFieldInAircraftTypes_inr.generate();
   rowFieldInRunwayConfigurations_rcf.generate();
   rowFieldInHourlyConfiguration_hcf.generate();
   rowFieldInSchedule_ags.generate();
   rowFieldInRunwaySet0_rst1.generate();
   rowFieldInAprons_apr1.generate();

   rowFieldOutstatistics_out.backup();
   rowFieldOutRunSets_rso.backup();

}

void execute()
{
   wrapper.getRunShare().run("C:\\MACAD2bis\\Executables\\macad2 -1b
C:\\MACAD2bis\\Input\\Master.in");
}

void parse()
{
   rowFieldOutstatistics_out.parse();
   rowFieldOutRunSets_rso.parse();

}

/**************************************************
 * End of auto-generated code
 **************************************************/
```

APPENDIX D

MODELING & SIMULATION ENVIRONMENT

D.1 A Review of Variables used in System Dynamics Models from Previous Air Transportation Studies

Table D.1: Variables Characterizing Airport Operations and Air Service

Variables	Studies
Congestion	[287, 203, 35, 222, 224, 225]
Congestion Threshold	[222, 224, 225]
Pressure to Reduce Congestion	[35]
Average Number of Flights per Day	[287, 203, 35, 143, 222, 224, 225]
Aircraft per Hour	[222, 225]
Types of Movement (departures vs. arrivals)	[209]
Peak Hours	[222, 224, 225]
Delays	[203, 35, 222, 224, 225]
Aircraft Models and Types	[209]
Types of Flights (Domestic vs. International	[209]
Commercial Operations GA/Non Commercial Operations	[35]
Airport Infrastructure	[35]
Resources Adequacy	[35]
Airport Capacity	[35]
Runway Capacity	[222, 224, 225]
Years to increase capacity	[222, 224, 225]
Amounts of Capacity Increase	[222, 224, 225]
Rate of Capacity Delivery	[222, 224, 225]
Airport Development Required	[35]
Ramp for Max Annual Airport Conversions	[133]
Base Year non SATS Airports	[133]
Time Period for non SATS Airports	[133]
Annual New non SATS Airports	[133]
First Year for SATS Airports	[133]
SATS Airport Conversion	[133]

Table D.2: Variables Characterizing Demand

Variables	**Studies**
Annual Demand Growth Rate	[224, 225]
Price Elasticity of Demand	[287, 203, 222, 224, 225]
Time Elasticity of Demand	[287, 222, 224, 225]
Frequency Elasticity	[203]
Level of Service and Level of Service Impact	[287, 35, 222, 224, 225, 303]
Demand for SATS Services	[303]
Airport Attractiveness to Passengers	[35]
Regional Attractiveness	[303]
Modal Choices Made by Passengers (Train, Car, etc.)	[196, 35, 143, 303]
Competition between Airports in Close Proximity	[143]
Local community complaints	[35]

Table D.3: Variables Characterizing the Economy

Variables	**Studies**
Growth Domestic Product (GDP)	[287, 143]
GDP Elasticity	[203]
Personal Income	[203]
Buyer Power Impact	[143]
Income Distribution	[143]
Employment Composition	[143]
Regional Jobs	[303]
Structure of the Local Production Sector	[143]
Inflation Rate	[287]
Fuel Price	[203]
Interest Rate	[203]

Table D.4: Variables Characterizing Airport Finances

Variables	**Studies**
Airport Revenues	[222, 224, 225]
SATS Revenues	[303]
Passenger Facility Charges (PFC)	[222, 224, 225]
Evaluation of Outcomes	[196]
Operating Cost Growth Factor	[133]
Average Annual Increase in Grants in Aid	[133]
Base Year Grants in Aid	[133]
Ramp Increase in 200X and 200Y	[133]
Average Annual Increase in AC Tax Revenue	[133]
Average Annual Increase in Grants in Aid	[133]
Base Year Tax Revenue per AT, GA, or SATS Aircraft	[133]
Average Annual Increase in AT, GA or SATS Tax Revenue	[133]

Table D.5: Variables Characterizing Technologies

Variables	**Studies**
Replacement Rate	[133]
Installation Rate	[133]
Maintenance Costs	[222, 224, 225]
Unit Maintenance Costs	[222, 224, 225]
Delivery Costs	[222, 224, 225]
Unit Delivery Costs	[222, 224, 225]

D.2 *Enhanced Entity-Relationship (EER) model of the M&S Environment*

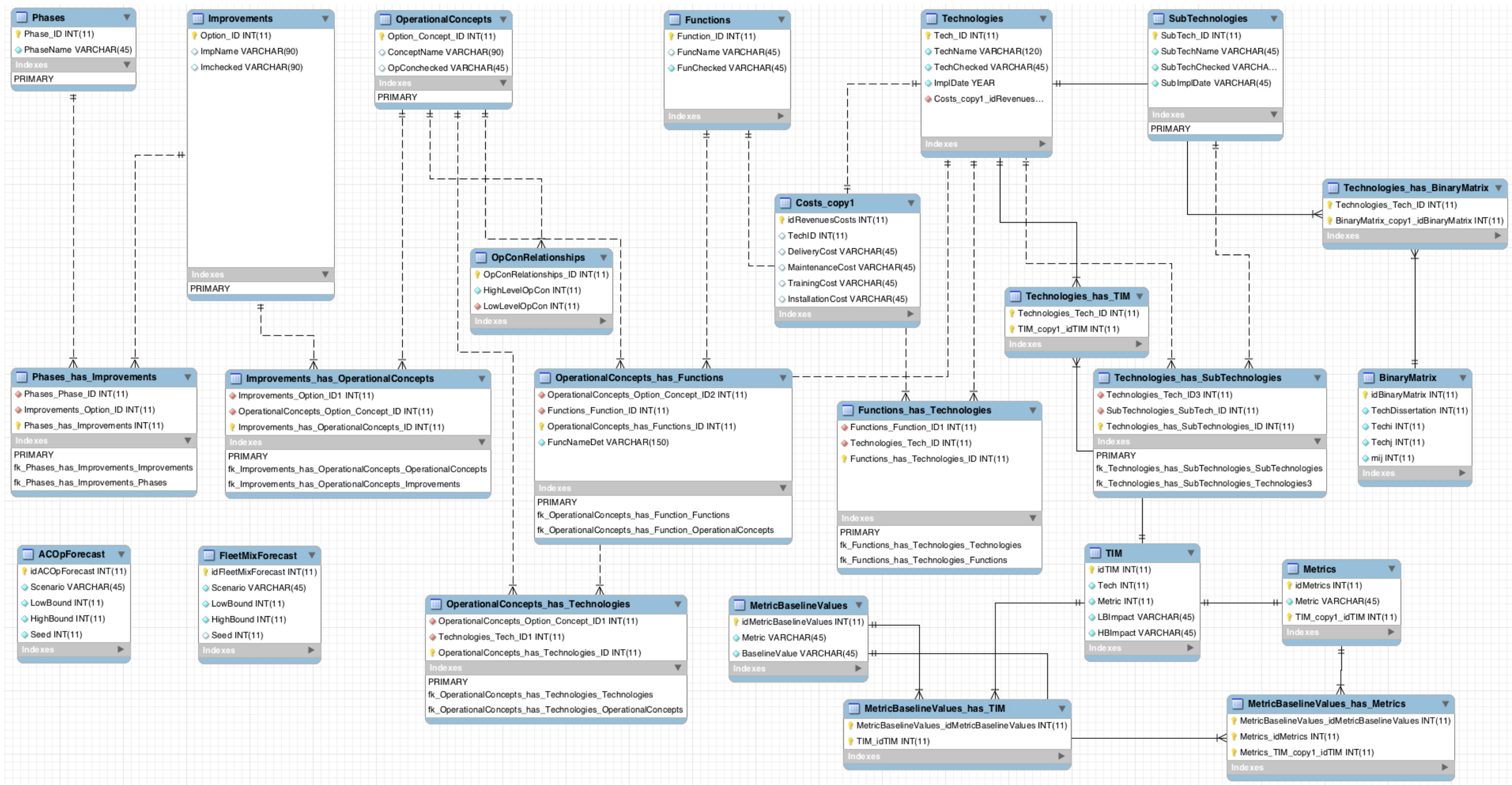


Figure D.1: Enhanced Entity-Relationship (EER) model.

D.3 Sensitivity Analysis at the System Level

Term	Orthog Estimate
Number of arrivals	111549.6
Percentage of small aircraft	103222.0
(Average total delay per aircraft-24.3971)*(Average total delay per aircraft-24.3971)	-59126.6
Average total delay per aircraft	-58006.1
Congestion threshold	-24301.6
(Number of arrivals-119.797)*(Percentage of small aircraft-64.9576)	14392.2
(Average total delay per aircraft-24.3971)*(Number of arrivals-119.797)	-8312.8
(Average total delay per aircraft-24.3971)*(Percentage of small aircraft-64.9576)	-7422.0
(Congestion threshold-0.0749)*(Congestion threshold-0.0749)	6765.3
(Average total delay per aircraft-24.3971)*(Congestion threshold-0.0749)	6441.3
(Congestion threshold-0.0749)*(Percentage of small aircraft-64.9576)	-3731.7
(Congestion threshold-0.0749)*(Number of arrivals-119.797)	-3616.4
Number of departures	-2421.3
(Number of departures-120.064)*(Percentage of small aircraft-64.9576)	-2212.2
Total arrival capacity	1436.0
(Congestion threshold-0.0749)*(Total arrival capacity-338.115)	-1077.9
(Number of departures-120.064)*(Total departure capacity-489.964)	1007.9
Total departure capacity	978.9
(Number of arrivals-119.797)*(Total arrival capacity-338.115)	-903.7
(Total arrival capacity-338.115)*(Total departure capacity-489.964)	-834.7
(Percentage of small aircraft-64.9576)*(Total arrival capacity-338.115)	834.0
(Number of departures-120.064)*(Number of departures-120.064)	-664.9
(Total departure capacity-489.964)*(Total departure capacity-489.964)	563.2
(Average total delay per aircraft-24.3971)*(Total departure capacity-489.964)	-462.1
(Percentage of small aircraft-64.9576)*(Total departure capacity-489.964)	424.3
(Percentage of small aircraft-64.9576)*(Percentage of small aircraft-64.9576)	-343.5
(Average total delay per aircraft-24.3971)*(Total arrival capacity-338.115)	335.8
(Average total delay per aircraft-24.3971)*(Number of departures-120.064)	-271.7
(Total arrival capacity-338.115)*(Total arrival capacity-338.115)	225.2
(Congestion threshold-0.0749)*(Number of departures-120.064)	-208.1
(Number of arrivals-119.797)*(Number of departures-120.064)	-122.4
(Number of departures-120.064)*(Total arrival capacity-338.115)	-94.9
(Congestion threshold-0.0749)*(Total departure capacity-489.964)	-60.7
(Number of arrivals-119.797)*(Number of arrivals-119.797)	-55.7
(Number of arrivals-119.797)*(Total departure capacity-489.964)	-49.5

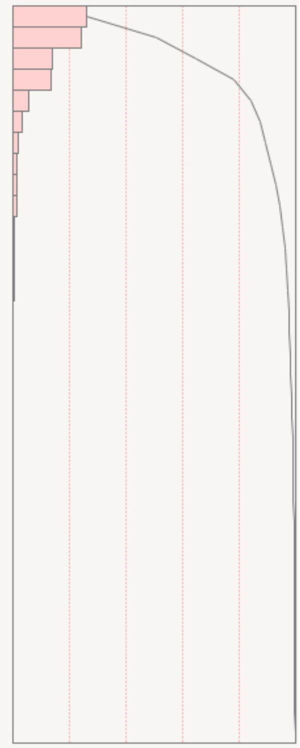


Figure D.2: Results of sensitivity analysis on revenues (key variables).

Term	Orthog Estimate
Total departure capacity	123.5845
Total arrival capacity	73.0737
Number of departures	-1.5446
Congestion threshold	-1.4917
Average total delay per aircraft	0.7756
Percentage of small aircraft	0.5253
Number of arrivals	0.4562
(Number of departures-120.064)*(Number of departures-120.064)	-2.8876e-5
(Number of arrivals-119.797)*(Percentage of small aircraft-64.9576)	-0.0000288
(Average total delay per aircraft-24.3971)*(Number of departures-120.064)	-0.0000229
(Number of departures-120.064)*(Total arrival capacity-338.115)	2.17044e-5
(Total departure capacity-489.964)*(Total departure capacity-489.964)	-0.0000195
(Number of arrivals-119.797)*(Number of arrivals-119.797)	1.75584e-5
(Number of departures-120.064)*(Total departure capacity-489.964)	1.61778e-5
(Congestion threshold-0.0749)*(Number of arrivals-119.797)	-1.5869e-5
(Average total delay per aircraft-24.3971)*(Average total delay per aircraft-24.3971)	-1.5527e-5
(Average total delay per aircraft-24.3971)*(Congestion threshold-0.0749)	-1.527e-5
(Number of departures-120.064)*(Percentage of small aircraft-64.9576)	-1.2449e-5
(Congestion threshold-0.0749)*(Total departure capacity-489.964)	-1.0319e-5
(Average total delay per aircraft-24.3971)*(Percentage of small aircraft-64.9576)	7.63782e-6
(Average total delay per aircraft-24.3971)*(Total departure capacity-489.964)	7.40658e-6
(Number of arrivals-119.797)*(Total departure capacity-489.964)	6.58306e-6
(Percentage of small aircraft-64.9576)*(Total arrival capacity-338.115)	-4.9044e-6
(Congestion threshold-0.0749)*(Percentage of small aircraft-64.9576)	-4.7697e-6
(Congestion threshold-0.0749)*(Number of departures-120.064)	4.19844e-6
(Percentage of small aircraft-64.9576)*(Percentage of small aircraft-64.9576)	-3.6253e-6
(Percentage of small aircraft-64.9576)*(Total departure capacity-489.964)	-2.8925e-6
(Total arrival capacity-338.115)*(Total arrival capacity-338.115)	-2.7661e-6
(Number of arrivals-119.797)*(Number of departures-120.064)	2.70763e-6
(Congestion threshold-0.0749)*(Total arrival capacity-338.115)	-1.9016e-6
(Congestion threshold-0.0749)*(Congestion threshold-0.0749)	-1.3376e-6
(Average total delay per aircraft-24.3971)*(Total arrival capacity-338.115)	1.31245e-6
(Number of arrivals-119.797)*(Total arrival capacity-338.115)	-7.4231e-7
(Total arrival capacity-338.115)*(Total departure capacity-489.964)	-3.996e-7
(Average total delay per aircraft-24.3971)*(Number of arrivals-119.797)	1.03206e-7

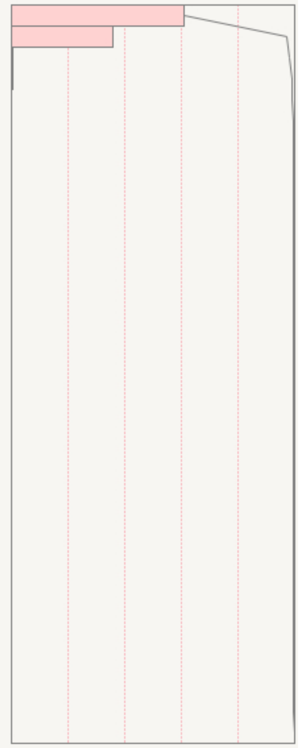
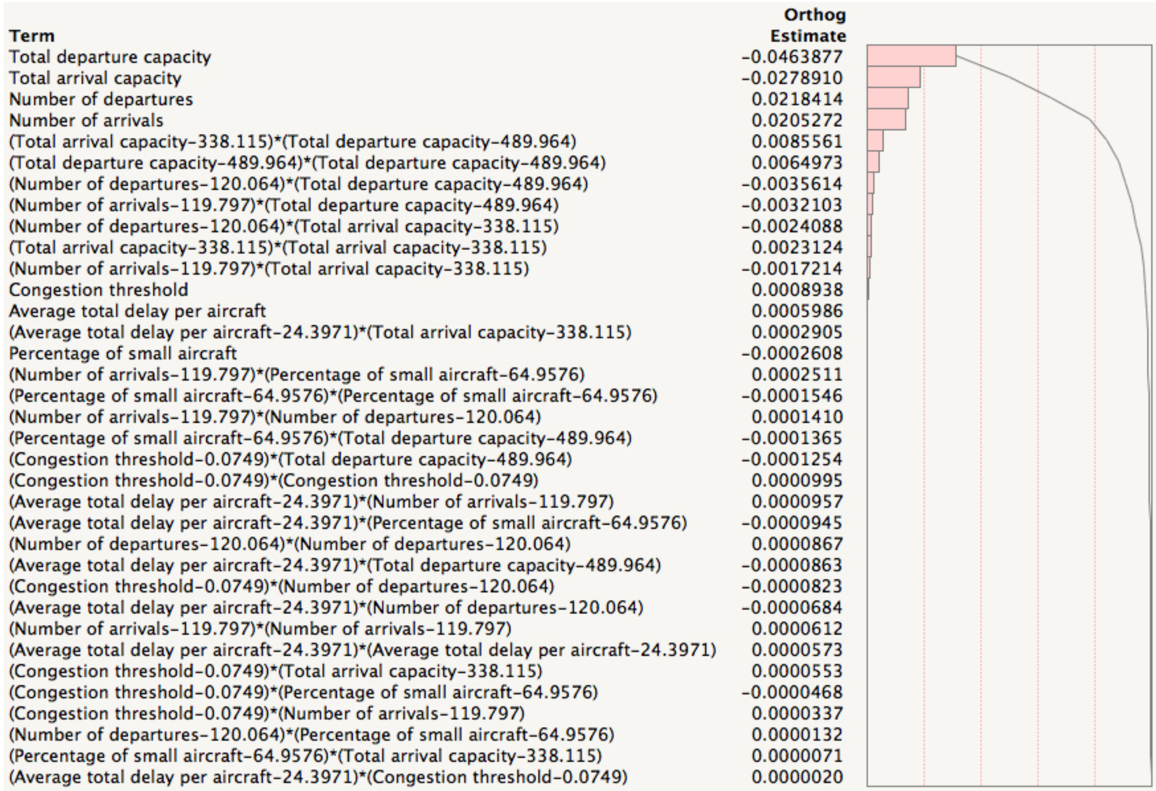


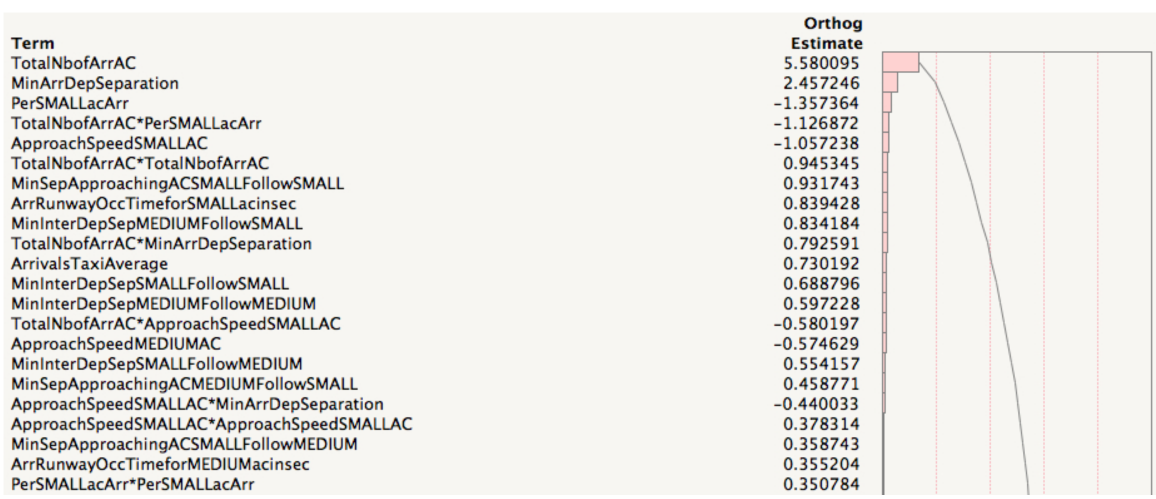
Figure D.3: Results of sensitivity analysis on capacity (key variables).



Term	Orthog Estimate
Total departure capacity	-0.0463877
Total arrival capacity	-0.0278910
Number of departures	0.0218414
Number of arrivals	0.0205272
(Total arrival capacity-338.115)*(Total departure capacity-489.964)	0.0085561
(Total departure capacity-489.964)*(Total departure capacity-489.964)	0.0064973
(Number of departures-120.064)*(Total departure capacity-489.964)	-0.0035614
(Number of arrivals-119.797)*(Total departure capacity-489.964)	-0.0032103
(Number of departures-120.064)*(Total arrival capacity-338.115)	-0.0024088
(Total arrival capacity-338.115)*(Total arrival capacity-338.115)	0.0023124
(Number of arrivals-119.797)*(Total arrival capacity-338.115)	-0.0017214
Congestion threshold	0.0008938
Average total delay per aircraft	0.0005986
(Average total delay per aircraft-24.3971)*(Total arrival capacity-338.115)	0.0002905
Percentage of small aircraft	-0.0002608
(Number of arrivals-119.797)*(Percentage of small aircraft-64.9576)	0.0002511
(Percentage of small aircraft-64.9576)*(Percentage of small aircraft-64.9576)	-0.0001546
(Number of arrivals-119.797)*(Number of departures-120.064)	0.0001410
(Percentage of small aircraft-64.9576)*(Total departure capacity-489.964)	-0.0001365
(Congestion threshold-0.0749)*(Total departure capacity-489.964)	-0.0001254
(Congestion threshold-0.0749)*(Congestion threshold-0.0749)	0.0000995
(Average total delay per aircraft-24.3971)*(Number of arrivals-119.797)	0.0000957
(Average total delay per aircraft-24.3971)*(Percentage of small aircraft-64.9576)	-0.0000945
(Number of departures-120.064)*(Number of departures-120.064)	0.0000867
(Average total delay per aircraft-24.3971)*(Total departure capacity-489.964)	-0.0000863
(Congestion threshold-0.0749)*(Number of departures-120.064)	-0.0000823
(Average total delay per aircraft-24.3971)*(Number of departures-120.064)	-0.0000684
(Number of arrivals-119.797)*(Number of arrivals-119.797)	0.0000612
(Average total delay per aircraft-24.3971)*(Average total delay per aircraft-24.3971)	0.0000573
(Congestion threshold-0.0749)*(Total arrival capacity-338.115)	0.0000553
(Congestion threshold-0.0749)*(Percentage of small aircraft-64.9576)	-0.0000468
(Congestion threshold-0.0749)*(Number of arrivals-119.797)	0.0000337
(Number of departures-120.064)*(Percentage of small aircraft-64.9576)	0.0000132
(Percentage of small aircraft-64.9576)*(Total arrival capacity-338.115)	0.0000071
(Average total delay per aircraft-24.3971)*(Congestion threshold-0.0749)	0.0000020

Figure D.4: Results of sensitivity analysis on airside utilization ratio (key variables).

D.4 Sensitivity Analysis at the Technical Level



Term	Orthog Estimate
TotalNbofArrAC	5.580095
MinArrDepSeparation	2.457246
PerSMALLacArr	-1.357364
TotalNbofArrAC*PerSMALLacArr	-1.126872
ApproachSpeedSMALLAC	-1.057238
TotalNbofArrAC*TotalNbofArrAC	0.945345
MinSepApproachingACSMALLFollowSMALL	0.931743
ArrRunwayOccTimeforSMALLacinsec	0.839428
MinInterDepSepMEDIUMFollowSMALL	0.834184
TotalNbofArrAC*MinArrDepSeparation	0.792591
ArrivalsTaxiAverage	0.730192
MinInterDepSepSMALLFollowSMALL	0.688796
MinInterDepSepMEDIUMFollowMEDIUM	0.597228
TotalNbofArrAC*ApproachSpeedSMALLAC	-0.580197
ApproachSpeedMEDIUMAC	-0.574629
MinInterDepSepSMALLFollowMEDIUM	0.554157
MinSepApproachingACMEDIUMFollowSMALL	0.458771
ApproachSpeedSMALLAC*MinArrDepSeparation	-0.440033
ApproachSpeedSMALLAC*ApproachSpeedSMALLAC	0.378314
MinSepApproachingACSMALLFollowMEDIUM	0.358743
ArrRunwayOccTimeforMEDIUMacinsec	0.355204
PerSMALLacArr*PerSMALLacArr	0.350784

Figure D.5: Results of sensitivity analysis on average total delays (key variables).

Term	Orthog Estimate
MinArrDepSeparation	-59.78022
MinInterDepSepSMALLFollowSMALL	-22.89497
MinInterDepSepMEDIUMFollowSMALL	-20.58442
MinInterDepSepSMALLFollowMEDIUM	-20.57721
ArrRunwayOccTimeforSMALLacinsec	-19.13055
MinInterDepSepMEDIUMFollowMEDIUM	-17.37068
ApproachSpeedSMALLAC	12.59087
MinArrDepSeparation*MinArrDepSeparation	12.36582
PerSMALLacArr	-10.53372
ArrRunwayOccTimeforSMALLacinsec*MinArrDepSeparation	7.11153
ArrRunwayOccTimeforMEDIUMacinsec	-6.00991
MinSepApproachingACSMALLFollowMEDIUM	5.60967
ArrRunwayOccTimeforMEDIUMacinsec*MinArrDepSeparation	4.89682
MinInterDepSepSMALLFollowSMALL*MinInterDepSepSMALLFollowMEDIUM	4.86120
DepRunwayOccTimeforSMALLacinsec*MinArrDepSeparation	4.79199
MinSepApproachingACSMALLFollowSMALL*MinArrDepSeparation	-4.65791
MinInterDepSepSMALLFollowSMALL*MinInterDepSepSMALLFollowSMALL	4.57018
ApproachSpeedSMALLAC*MinInterDepSepMEDIUMFollowSMALL	-4.55610
MinInterDepSepSMALLFollowSMALL*MinInterDepSepMEDIUMFollowMEDIUM	3.71447
DepTaxiAverage	3.48393

Figure D.6: Results of sensitivity analysis on total departure capacity (key variables).

Term	Orthog Estimate
MinArrDepSeparation	-28.76800
ApproachSpeedSMALLAC	16.76591
MinSepApproachingACSMALLFollowSMALL	-13.03987
ArrRunwayOccTimeforSMALLacinsec	-8.69381
MinInterDepSepSMALLFollowSMALL	-7.35186
MinSepApproachingACMEDIUMFollowSMALL	-6.73900
MinInterDepSepSMALLFollowMEDIUM	-6.68822
MinSepApproachingACMEDIUMFollowMEDIUM	-6.63229
ApproachSpeedMEDIUMAC	6.60864
MinSepApproachingACSMALLFollowMEDIUM	-6.58143
MinInterDepSepMEDIUMFollowSMALL	-6.49491
MinInterDepSepMEDIUMFollowMEDIUM	-5.41164
MinArrDepSeparation*MinArrDepSeparation	4.47531
ArrRunwayOccTimeforMEDIUMacinsec	-3.35650
DepRunwayOccTimeforMEDIUMacinsec	-3.15129
TotalNbofArrAC	-2.99972

Figure D.7: Results of sensitivity analysis on total arrival capacity (key variables).

APPENDIX E

VALUATION & SELECTION OF ADAPTABLE PORTFOLIOS

E.1 Descriptions of the Technologies Considered

E.1.1 Multi-Sensor Data Processor (MSDP)

A MSDP enables the fusion of surface movement radar(s), multilateration and ADS-B data to better estimate the location of a particular target and provide a better picture of terminal and surface traffic [263, 262]

E.1.2 Primary Surveillance Radar (PSR)

A PSR is a radar system that allows air traffic controller to monitor all aircraft in the airspace. As opposed to SSR, a PSR "operates totally independently of the target aircraft - that is, no action from the aircraft is required for it to provide a radar return" [316].

E.1.3 Multilateration (MLAT)

Multilateration is a beacon-based, ground-based independent cooperative surveillance system that provides target positive identification and location information throughout a defined coverage to an ATS facility [262, 164]. In certain regions of the World, it is used as a substitute for primary or secondary radar [19]. The benefits of MLAT are manifold and include, among others, the provision of surface and local surveillance for airports, and an increase in "airport safety and capacity, especially under low visibility conditions" [164]. Due to its high update rate, a MLAT also helps minimize waiting time for a following departure. MLAT can work as a back-up system for an existing SSR, or can provide additional information (such as target identification) to the one provided by a PSR. Another advantage of MLAT for airports is that it is less than half the cost of radar sensors [164], especially because of lower maintenance costs [293]. Its performance is also superior to that of a SSR [231].

E.1.4 Surface Movement Radar (SMR)

A SMR is a radar that supports air traffic controllers visual observations by detecting aircraft and vehicles on the surface of the airport

E.1.5 Legacy Secondary Surveillance Radar (SSR)

A SSR is a radar system that identifies a target and determines its altitude, range and azimuth by requesting additional information from the target itself [23, 331]

E.1.6 Human Machine Interface (HMI) related Technologies

HMI technologies represent the hardware, interfaces, or any type of medium that allows the user to interact with the machine or with the data/information it provides.

E.1.7 Ground/Ground Communications

Ground/ground communication technologies include enablers such as ground IP network, airport wireless communication infrastructure, ground integrated voice/data

E.1.8 Instrument Landing System (ILS)

An ILS is a precision approach system that “safely guide aircraft to the runway when the weather conditions do not allow for a visual approach and landing” [160]. In particular, “it provides the pilot with instrument indications which, when utilised in conjunction with the normal flight instruments, enables the aircraft to be manoeuvred along a precise, predetermined, final approach path” [57].

E.1.9 Departure MANager (DMAN)

A DMAN is a system that assists airport controllers in planning inbound and outbound traffic operations [34]. It is expected that airports equipped with a DMAN will experienced improved runway throughput (due to improved departure sequence), reduced queue length and taxi time [286]. In particular, a DMAN "automatically determines times for taxi clearance and take-off for each flight, and allows users to modify this schedule as desired. This tool integrates with existing information sources and other decision support tools, requiring minimum equipment investment and minimal changes to operational practice" [286].

E.1.10 Surface MANager (SMAN)

A SMAN is a system that "shall provide proper taxi paths and timing of ground movement operations according to planned departure schedule", as well as "support merging of departure streams accordingly to required departure sequence" [33]

E.1.11 Arrival MANager (AMAN)

An AMAN is a system that helps air traffic controller manage the flow of arriving traffic. As discussed in [109], "its main aims are to optimize the runway capacity (sequence) and/or to regulate/manage (meter) the flow of aircraft entering the airspace". AMAN supports the planning of taxi routes by providing estimated landing times [33]

E.1.12 Current Air/Ground Datalink Broadcast Technologies

Datalink technologies enable the transfer of digitized information to support communication, navigation and surveillance applications. Current air/ground datalink broadcast technologies include Universal Access Transceiver (UAT), 1090 Extended Squitter (ES), etc.

E.1.13 Current Air/Ground Datalink Point-to-point Technologies

As defined in [330], "a traditional point-to-point data link is a communications medium with exactly two endpoints and no data or packet formatting. The host computers at either end had to take full responsibility for formatting the data transmitted between them." Current air/ground datalink point to point technologies include High Frequency Data Link (HFDL), Very High Frequency Data Link Mode 2 (VDL2), etc.

APPENDIX F

MATLAB FILES

F.1 BaselineValuesAirport2.m

```
function [MetricsBV] = BaselineValuesAirport2()

%Connection to server and database
[dbConn] = ConnectToDB();

SQLqueryMetric = ['select idMetrics from Metrics'];
AllMetricsID = fetch(dbConn, SQLqueryMetric);
MetricsBV = zeros(length(AllMetricsID));
SQLqueryBaselineValues = ['select BaselineValueAirport2 from MetricBaselineValues'];
MetricsBV = fetch(dbConn, SQLqueryBaselineValues);

end
```

F.2 BaselineValues.m

```
function [MetricsBV] = BaselineValues()

%Connection to server and database
[dbConn] = ConnectToDB();

SQLqueryMetric = ['select idMetrics from Metrics'];
AllMetricsID = fetch(dbConn, SQLqueryMetric);
MetricsBV = zeros(length(AllMetricsID));
SQLqueryBaselineValues = ['select BaselineValue from MetricBaselineValues'];
MetricsBV = fetch(dbConn, SQLqueryBaselineValues);

end
```

F.3 ConnectToDB.m

```
function [dbConn] = ConnectToDB()

username = 'root';
password = 'XXXX';
dbName = 'TechSelection';
dbConn = database(dbName,username,password,'com.mysql.jdbc.Driver','jdbc:mysql
    ://172.16.20.87:3306/TechSelection');

end
```

F.4 ConnectToModelCenterClusterVersionS2.m

```
tic
clear all

TimebtwDecisions =15; %years
lengthrun = 15; %years
TotalNbofArrACInitial = 99;
PerSMALLacArrInitial  = 59;
time = zeros(1,TimebtwDecisions);
TotalNbofArrAC = zeros(1,TimebtwDecisions);
AvTotalDelay = zeros(1,TimebtwDecisions);
NbAC = zeros(1,TimebtwDecisions);
PerSmallAC = zeros(1,TimebtwDecisions);
TotArrCapacity = zeros(1,TimebtwDecisions);
TotDepCapacity =  zeros(1,TimebtwDecisions);
AvArrDelays =  zeros(1,TimebtwDecisions);
AvDepDelays = zeros(1,TimebtwDecisions);
NbDep = zeros(1,TimebtwDecisions);
NbArr = zeros(1,TimebtwDecisions);
DepUtilizationRatio = zeros(1,TimebtwDecisions);
ArrUtilizationRatio = zeros(1,TimebtwDecisions);
UtilizationRatio = zeros(1,TimebtwDecisions);
TotalAircraft = zeros(1,TimebtwDecisions);
TotalCapacity = zeros(1,TimebtwDecisions);
TotalUtilizationRatio = zeros(1,TimebtwDecisions);
AvRunwayCongDelay = zeros(1,TimebtwDecisions);
ArrCapacityperHour = zeros(1,TimebtwDecisions);
DepCapacityperHour = zeros(1,TimebtwDecisions);
DepRunwayUtilizationRatio = zeros(1,TimebtwDecisions);
ArrRunwayUtilizationRatio = zeros(1,TimebtwDecisions);

CongThreshold = 0.055;

%INTERACT WITH MACAD MODEL

[HBGrowthRate HBFleetMix LBGrowthRate LBFleetMix] = Traffic();

%To initialize COM client
```

```
mc = actxserver('ModelCenter.Application');

%To load MACAD model
invoke(mc,'loadModel','\\PINION-317\WorksInProgressWithoutSurrogate\MACAD2SoloDec2011.pxc'
    );

metricBaseline = BaselineValues();

invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ApproachSpeedSMALLAC', metricBaseline{1});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ApproachSpeedMEDIUMAC', metricBaseline{2})
    ;
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrRunwayOccTimeforSMALLacinsec',
    metricBaseline{3});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrRunwayOccTimeforMEDIUMacinsec',
    metricBaseline{4});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepRunwayOccTimeforSMALLacinsec',
    metricBaseline{5});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepRunwayOccTimeforMEDIUMacinsec',
    metricBaseline{6});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrivalsTaxiAverage', metricBaseline{7});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepTaxiAverage', metricBaseline{8});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACSMALLFollowSMALL',
    metricBaseline{9});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACSMALLFollowMEDIUM',
    metricBaseline{10});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACMEDIUMFollowSMALL',
    metricBaseline{11});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACMEDIUMFollowMEDIUM',
    metricBaseline{12});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepSMALLFollowSMALL',
    metricBaseline{13});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepSMALLFollowMEDIUM',
    metricBaseline{14});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepMEDIUMFollowSMALL',
    metricBaseline{15});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepMEDIUMFollowMEDIUM',
    metricBaseline{16});
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinArrDepSeparation', metricBaseline{17});

%PASS VALUES TO VENSIM MODEL AND CONTINUE
```

```
TotalNbRuns = 500;


AllAvTotDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllArrUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllDepUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalAircraft = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllDepRunwayUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllArrRunwayUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllNbDep = zeros(TotalNbRuns,TimebtwDecisions);
AllNbArr = zeros(TotalNbRuns,TimebtwDecisions);
AllPerSmallAC = zeros(TotalNbRuns,TimebtwDecisions);
AllNbAC = zeros(TotalNbRuns,TimebtwDecisions);
AllTotArrCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllTotDepCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllAvArrDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllAvDepDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllAvRunwayCongDelay = zeros(TotalNbRuns,TimebtwDecisions);
AllDepCapacityperHour = zeros(TotalNbRuns,TimebtwDecisions);
AllArrCapacityperHour = zeros(TotalNbRuns,TimebtwDecisions);


AverageofAverageTotalDelay = zeros(1,TimebtwDecisions);
AverageofArrUtilizationRatio = zeros(1,TimebtwDecisions);
AverageofDepUtilizationRatio = zeros(1,TimebtwDecisions);
AverageofTotalAircraft = zeros(1,TimebtwDecisions);
AverageofTotalCapacity = zeros(1,TimebtwDecisions);
AverageofTotalUtilizationRatio = zeros(1,TimebtwDecisions);
AverageofDepRunwayUtilizationRatio = zeros(1,TimebtwDecisions);
AverageofArrRunwayUtilizationRatio = zeros(1,TimebtwDecisions);
AverageofNbDep = zeros(1,TimebtwDecisions);
AverageofNbArr = zeros(1,TimebtwDecisions);
AverageofPerSmallAC = zeros(1,TimebtwDecisions);
AverageofNbAC = zeros(1,TimebtwDecisions);
AverageofTotArrCapacity =  zeros(1,TimebtwDecisions);
AverageofTotDepCapacity =  zeros(1,TimebtwDecisions);
AverageofArrDelays =  zeros(1,TimebtwDecisions);
AverageofDepDelays =  zeros(1,TimebtwDecisions);
AverageofAvRunwayCongDelay = zeros(1,TimebtwDecisions);
AverageofDepCapacityperHour = zeros(1,TimebtwDecisions);
AverageofArrCapacityperHour = zeros(1,TimebtwDecisions);
```

```
AverageofAverageTotalDelayS2 = zeros(1,TimebtwDecisions);
AverageofArrUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofDepUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofTotalAircraftS2 = zeros(1,TimebtwDecisions);
AverageofTotalCapacityS2 = zeros(1,TimebtwDecisions);
AverageofTotalUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofDepRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofArrRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofNbDepS2 = zeros(1,TimebtwDecisions);
AverageofNbArrS2 = zeros(1,TimebtwDecisions);
AverageofPerSmallACS2 = zeros(1,TimebtwDecisions);
AverageofNbACS2 = zeros(1,TimebtwDecisions);
AverageofTotArrCapacityS2 =  zeros(1,TimebtwDecisions);
AverageofTotDepCapacityS2 =  zeros(1,TimebtwDecisions);
AverageofArrDelaysS2 =  zeros(1,TimebtwDecisions);
AverageofDepDelaysS2 =  zeros(1,TimebtwDecisions);
AverageofAvRunwayCongDelayS2 = zeros(1,TimebtwDecisions);
AverageofDepCapacityperHourS2 = zeros(1,TimebtwDecisions);
AverageofArrCapacityperHourS2 = zeros(1,TimebtwDecisions);

FinalAverageTotalDelayS2 = zeros(1,TimebtwDecisions);
FinalArrUtilizationRatioS2 = zeros(1,TimebtwDecisions);
FinalDepUtilizationRatioS2 = zeros(1,TimebtwDecisions);
FinalTotalAircraftS2 = zeros(1,TimebtwDecisions);
FinalTotalCapacityS2 = zeros(1,TimebtwDecisions);
FinalTotalUtilizationRatioS2 = zeros(1,TimebtwDecisions);
FinalDepRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
FinalArrRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
FinalNbDepS2 = zeros(1,TimebtwDecisions);
FinalNbArrS2 = zeros(1,TimebtwDecisions);
FinalPerSmallACS2 = zeros(1,TimebtwDecisions);
FinalNbACS2 = zeros(1,TimebtwDecisions);
FinalTotArrCapacityS2 = zeros(1,TimebtwDecisions);
FinalTotDepCapacityS2 = zeros(1,TimebtwDecisions);
FinalArrDelaysS2 = zeros(1,TimebtwDecisions);
FinalDepDelaysS2 = zeros(1,TimebtwDecisions);
FinalAvRunwayCongDelayS2 = zeros(1,TimebtwDecisions);
FinalDepCapacityperHourS2 = zeros(1,TimebtwDecisions);
FinalArrCapacityperHourS2 = zeros(1,TimebtwDecisions);
```

```
for run = 1:TotalNbRuns

     TotalNbofArrACInitial = 99;
     PerSMALLacArrInitial  = 59;

      for i=1:1:5

         GRrandom = str2double(LBGrowthRate{1}) + rand(1,1) * (str2double(HBGrowthRate{1})
              - str2double(LBGrowthRate{1}));  %Uniform distribution between the bound set
              in database
         FMrandom = str2double(LBFleetMix{1}) + rand(1,1) * (str2double(HBFleetMix{1}) -
             str2double(LBFleetMix{1})); %Uniform distribution between the bound set in
             database

         TotalNbofArrAC(i) =  TotalNbofArrACInitial + TotalNbofArrACInitial * GRrandom
             /100;
         PerSMALLacArr(i) =  PerSMALLacArrInitial +  PerSMALLacArrInitial * FMrandom/100;

         %Assign values to traffic inputs
         invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.TotalNbofArrAC',TotalNbofArrAC(i)
             );
         invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.PerSMALLacArr',PerSMALLacArr(i));

         TotalNbofArrACInitial = TotalNbofArrAC(i);
         PerSMALLacArrInitial = PerSMALLacArr(i);

         %Run MACAD and retrieve outputs of interest
         NbAC(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.TotalNbofArrAC');
         PerSmallAC(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.PerSMALLacArr');
         AvTotalDelay(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvTotalDelays')
             ;
         TotArrCapacity(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
             TotArrCapacity');
         TotDepCapacity(i) =  invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
             TotDepCapacity');
         AvArrDelays(i) =  invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvArrDelays');
         AvDepDelays(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvDepDelay');
         AvRunwayCongDelay(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
             AvRunwayCongDelay');
         NbDep(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.NbDep');
```

```
    NbArr(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.NbArrivals');
    ArrCapacityperHour(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        ArrivalCapacityperHourEvenMix');
    DepCapacityperHour(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        DepartureCapacityperHourEvenMix');

    % Calculate utilizatio ratios
    DepUtilizationRatio(i) = NbDep(i)/ TotDepCapacity(i);
    ArrUtilizationRatio(i) = NbArr(i)/TotArrCapacity(i);
    DepRunwayUtilizationRatio(i) = NbDep(i) / (DepCapacityperHour(i) * 18);
    ArrRunwayUtilizationRatio(i) = NbArr(i) / (ArrCapacityperHour(i) * 18);
    TotalAircraft(i) = NbDep(i)+ NbArr(i);
    TotalCapacity(i) = TotDepCapacity(i)+TotArrCapacity(i);
    TotalUtilizationRatio(i) = TotalAircraft(i)/TotalCapacity(i);

 end

AllAvTotDelays(run,:) = AvTotalDelay;
AllArrUtilizationRatio(run,:) = ArrUtilizationRatio;
AllDepUtilizationRatio(run,:) = DepUtilizationRatio;
AllDepRunwayUtilizationRatio(run,:) = DepRunwayUtilizationRatio;
AllArrRunwayUtilizationRatio(run,:) = ArrRunwayUtilizationRatio;
AllTotalAircraft(run,:) = TotalAircraft;
AllTotalCapacity(run,:) = TotalCapacity;
AllTotalUtilizationRatio(run,:) = TotalUtilizationRatio;
AllNbDep(run,:) = NbDep;
AllNbArr(run,:) = NbArr;
AllPerSmallAC(run,:) = PerSmallAC;
AllNbAC(run,:) = NbAC;
AllTotArrCapacity(run,:) = TotArrCapacity;
AllTotDepCapacity(run,:) = TotDepCapacity;
AllAvArrDelays(run,:) = AvArrDelays;
AllAvDepDelays(run,:) = AvDepDelays;
AllAvRunwayCongDelay(run,:) = AvRunwayCongDelay;
AllDepCapacityperHour(run,:) = DepCapacityperHour;
AllArrCapacityperHour(run,:) = ArrCapacityperHour;



AverageofAverageTotalDelay = AverageofAverageTotalDelay + AllAvTotDelays(run,:);
AverageofArrUtilizationRatio = AverageofArrUtilizationRatio + AllArrUtilizationRatio(
    run,:);
```

```
    AverageofDepUtilizationRatio = AverageofDepUtilizationRatio + AllDepUtilizationRatio(
        run,:);
    AverageofTotalAircraft = AverageofTotalAircraft +  AllTotalAircraft(run,:);
    AverageofTotalCapacity = AverageofTotalCapacity +  AllTotalCapacity(run,:);
    AverageofTotalUtilizationRatio = AverageofTotalUtilizationRatio +
        AllTotalUtilizationRatio(run,:);
    AverageofDepRunwayUtilizationRatio = AverageofDepRunwayUtilizationRatio +
        AllDepRunwayUtilizationRatio(run,:);
    AverageofArrRunwayUtilizationRatio = AverageofArrRunwayUtilizationRatio +
        AllArrRunwayUtilizationRatio(run,:);
    AverageofNbDep = AverageofNbDep + AllNbDep(run,:);
    AverageofNbArr = AverageofNbArr  + AllNbArr(run,:);
    AverageofPerSmallAC = AverageofPerSmallAC + AllPerSmallAC(run,:);
    AverageofNbAC = AverageofNbAC + AllNbAC(run,:);
    AverageofTotArrCapacity =  AverageofTotArrCapacity + AllTotArrCapacity(run,:);
    AverageofTotDepCapacity =  AverageofTotDepCapacity + AllTotDepCapacity(run,:);
    AverageofArrDelays =  AverageofArrDelays + AllAvArrDelays(run,:);
    AverageofDepDelays =  AverageofDepDelays + AllAvDepDelays(run,:);
    AverageofAvRunwayCongDelay = AverageofAvRunwayCongDelay + AllAvRunwayCongDelay(run,:)
        ;
    AverageofDepCapacityperHour = AverageofDepCapacityperHour + AllDepCapacityperHour(run
        ,:);
    AverageofArrCapacityperHour = AverageofArrCapacityperHour + AllArrCapacityperHour(run
        ,:);

    run = run+1;

end

AverageofAverageTotalDelay = AverageofAverageTotalDelay/TotalNbRuns;
AverageofArrUtilizationRatio = AverageofArrUtilizationRatio/TotalNbRuns;
AverageofDepUtilizationRatio = AverageofDepUtilizationRatio/TotalNbRuns;
AverageofTotalAircraft  = AverageofTotalAircraft/TotalNbRuns;
AverageofTotalCapacity = AverageofTotalCapacity/TotalNbRuns;
AverageofTotalUtilizationRatio = AverageofTotalUtilizationRatio/TotalNbRuns;
AverageofDepRunwayUtilizationRatio = AverageofDepRunwayUtilizationRatio/TotalNbRuns;
AverageofArrRunwayUtilizationRatio = AverageofArrRunwayUtilizationRatio/TotalNbRuns;
AverageofNbDep = AverageofNbDep/TotalNbRuns;
AverageofNbArr = AverageofNbArr/TotalNbRuns;
AverageofPerSmallAC = AverageofPerSmallAC/TotalNbRuns;
AverageofNbAC = AverageofNbAC/TotalNbRuns;
```

```
AverageofTotArrCapacity = AverageofTotArrCapacity/TotalNbRuns;
AverageofTotDepCapacity = AverageofTotDepCapacity/TotalNbRuns;
AverageofArrDelays = AverageofArrDelays/TotalNbRuns;
AverageofDepDelays = AverageofDepDelays/TotalNbRuns;
AverageofAvRunwayCongDelay = AverageofAvRunwayCongDelay/TotalNbRuns;
AverageofDepCapacityperHour = AverageofDepCapacityperHour/TotalNbRuns;
AverageofArrCapacityperHour = AverageofArrCapacityperHour/TotalNbRuns;

 % Save data in Excel spreadsheet
  xlswrite('5yearswithnoTechS2.xls', [AverageofAverageTotalDelay],'AverageTotalDelay');
  xlswrite('5yearswithnoTechS2.xls', [AverageofArrUtilizationRatio],'ArrUtilizationRatio')
      ;
  xlswrite('5yearswithnoTechS2.xls', [AverageofDepUtilizationRatio],'DepUtilizationRatio')
      ;
  xlswrite('5yearswithnoTechS2.xls', [AverageofTotalAircraft],'TotalAircraft');
  xlswrite('5yearswithnoTechS2.xls', [AverageofTotalCapacity],'TotalCapacity');
  xlswrite('5yearswithnoTechS2.xls', [AverageofTotalUtilizationRatio],'
      TotalUtilizationRatio');
  xlswrite('5yearswithnoTechS2.xls', [AverageofDepRunwayUtilizationRatio],'
      DepRunwayUtilizationRatio');
  xlswrite('5yearswithnoTechS2.xls', [AverageofArrRunwayUtilizationRatio],'
      ArrRunwayUtilizationRatio');
  xlswrite('5yearswithnoTechS2.xls', [AverageofNbDep],'NbDep');
  xlswrite('5yearswithnoTechS2.xls', [AverageofNbArr],'NbArr');
  xlswrite('5yearswithnoTechS2.xls', [AverageofPerSmallAC],'PerSmallAC');
  xlswrite('5yearswithnoTechS2.xls', [AverageofNbAC],'NbAC');
  xlswrite('5yearswithnoTechS2.xls', [AverageofTotArrCapacity],'TotArrCapacity');
  xlswrite('5yearswithnoTechS2.xls', [AverageofTotDepCapacity],'TotDepCapacity');
  xlswrite('5yearswithnoTechS2.xls', [AverageofArrDelays],'ArrDelays');
  xlswrite('5yearswithnoTechS2.xls', [AverageofDepDelays],'DepDelays'); %
  xlswrite('5yearswithnoTechS2.xls', [AverageofAvRunwayCongDelay],'AvRunwayCongDelay');
  xlswrite('5yearswithnoTechS2.xls', [AverageofDepCapacityperHour],'DepCapacityperHour');
  xlswrite('5yearswithnoTechS2.xls', [AverageofArrCapacityperHour],'ArrCapacityperHour');

 MaxAC =  AverageofNbAC(5);
 MaxPerc = AverageofPerSmallAC(5);

%INVESTIGATE INVESTMENT OPTIONS AT YEAR 5

year = 2010;
[TechInPlace] = InPlaceBaseline();
```

```
[NbPortfoliosT5, Portfolio, TotalImpact, TechInPlaceT5] = PortfolioImpact(year,TechInPlace
    );

for k=1:NbPortfoliosT5 %k is the number of portfolio
    MetricBaseline = BaselineValues();

    %Calculate value of new metric based on impact of portfolio
    for j=1:1:length(MetricBaseline)   %j is the metric id
        NewImpact(k,j) = str2double(MetricBaseline(j,:)) + str2double(MetricBaseline(j,:))
            *TotalImpact(k,j);
    end

     %Run MACAD with the new variables
     [AverageofAverageTotalDelayS2, AverageofArrUtilizationRatioS2,
         AverageofDepUtilizationRatioS2, AverageofTotalAircraftS2,
         AverageofTotalCapacityS2, AverageofTotalUtilizationRatioS2,
         AverageofDepRunwayUtilizationRatioS2, AverageofArrRunwayUtilizationRatioS2,
         AverageofNbDepS2, AverageofNbArrS2, AverageofPerSmallACS2, AverageofNbACS2,
         AverageofTotArrCapacityS2, AverageofTotDepCapacityS2, AverageofArrDelaysS2,
         AverageofDepDelaysS2, AverageofAvRunwayCongDelayS2, AverageofDepCapacityperHourS2
         , AverageofArrCapacityperHourS2]=RunT5(MaxAC,MaxPerc,k,NewImpact,NbPortfoliosT5);

     FinalAverageTotalDelayS2(k,:) = AverageofAverageTotalDelayS2;
     FinalArrUtilizationRatioS2(k,:) = AverageofArrUtilizationRatioS2;
     FinalDepUtilizationRatioS2(k,:) = AverageofDepUtilizationRatioS2;
     FinalTotalAircraftS2(k,:) = AverageofTotalAircraftS2;
     FinalTotalCapacityS2(k,:) = AverageofTotalCapacityS2;
     FinalTotalUtilizationRatioS2(k,:) = AverageofTotalUtilizationRatioS2;
     FinalDepRunwayUtilizationRatioS2(k,:) = AverageofDepRunwayUtilizationRatioS2;
     FinalArrRunwayUtilizationRatioS2(k,:) = AverageofArrRunwayUtilizationRatioS2;
     FinalNbDepS2(k,:) = AverageofNbDepS2;
     FinalNbArrS2(k,:) = AverageofNbArrS2;
     FinalPerSmallACS2(k,:) = AverageofPerSmallACS2;
     FinalNbACS2(k,:) = AverageofNbACS2;
     FinalTotArrCapacityS2(k,:) = AverageofTotArrCapacityS2;
     FinalTotDepCapacityS2(k,:) = AverageofTotDepCapacityS2;
     FinalArrDelaysS2(k,:) = AverageofArrDelaysS2;
     FinalDepDelaysS2(k,:) = AverageofDepDelaysS2;
     FinalAvRunwayCongDelayS2(k,:) = AverageofAvRunwayCongDelayS2;
     FinalDepCapacityperHourS2(k,:) =AverageofDepCapacityperHourS2;
     FinalArrCapacityperHourS2(k,:) = AverageofArrCapacityperHourS2;
```

```
end

 % Save data in Excel spreadsheet
  xlswrite('10yearswithTechS2.xls', [FinalAverageTotalDelayS2],'AverageTotalDelay');
  xlswrite('10yearswithTechS2.xls', [FinalArrUtilizationRatioS2],'ArrUtilizationRatio');
  xlswrite('10yearswithTechS2.xls', [FinalDepUtilizationRatioS2],'DepUtilizationRatio');
  xlswrite('10yearswithTechS2.xls', [FinalTotalAircraftS2],'TotalAircraft');
  xlswrite('10yearswithTechS2.xls', [FinalTotalCapacityS2],'TotalCapacity');
  xlswrite('10yearswithTechS2.xls', [FinalTotalUtilizationRatioS2],'TotalUtilizationRatio'
      );
  xlswrite('10yearswithTechS2.xls', [FinalDepRunwayUtilizationRatioS2],'
      DepRunwayUtilizationRatio');
  xlswrite('10yearswithTechS2.xls', [FinalArrRunwayUtilizationRatioS2],'
      ArrRunwayUtilizationRatio');
  xlswrite('10yearswithTechS2.xls', [FinalNbDepS2],'NbDep');
  xlswrite('10yearswithTechS2.xls', [FinalNbArrS2],'NbArr');
  xlswrite('10yearswithTechS2.xls', [FinalPerSmallACS2],'PerSmallAC');
  xlswrite('10yearswithTechS2.xls', [FinalNbACS2],'NbAC');
  xlswrite('10yearswithTechS2.xls', [FinalTotArrCapacityS2],'TotArrCapacity');
  xlswrite('10yearswithTechS2.xls', [FinalTotDepCapacityS2],'TotDepCapacity');
  xlswrite('10yearswithTechS2.xls', [FinalArrDelaysS2],'ArrDelays');
  xlswrite('10yearswithTechS2.xls', [FinalDepDelaysS2],'DepDelays');
  xlswrite('10yearswithTechS2.xls', [FinalAvRunwayCongDelayS2],'AvRunwayCongDelay');
  xlswrite('10yearswithTechS2.xls', [FinalDepCapacityperHourS2],'DepCapacityperHour');
  xlswrite('10yearswithTechS2.xls', [FinalArrCapacityperHourS2],'ArrCapacityperHour');

 toc
```

F.5 ConnectToVensimDesktopVersionWithTechS2.m

```
tic
clear all

TimebtwDecisions = 1; %years
lengthrun = 10; %years
TotalPortf = 3500;

AvTotalDelay = zeros(1,lengthrun);
NbAC = zeros(1,lengthrun);
PerSmallAC = zeros(1,lengthrun);
TotArrCapacity = zeros(1,lengthrun);
TotDepCapacity =  zeros(1,lengthrun);
AvArrDelays =  zeros(1,lengthrun);
AvDepDelays = zeros(1,lengthrun);
NbDep = zeros(1,lengthrun);
NbArr = zeros(1,lengthrun);
DepUtilizationRatio = zeros(1,lengthrun);
ArrUtilizationRatio = zeros(1,lengthrun);
TotalAircraft = zeros(1,lengthrun);
TotalCapacity = zeros(1,lengthrun);
TotalUtilizationRatio = zeros(1,lengthrun);
AvRunwayCongDelay = zeros(1,lengthrun);
ArrCapacityperHour = zeros(1,lengthrun);
DepCapacityperHour = zeros(1,lengthrun);
DepRunwayUtilizationRatio = zeros(1,lengthrun);
ArrRunwayUtilizationRatio = zeros(1,lengthrun);

CongThreshold = 0.055;

%Init for Vensim value retrieval
NbofACV = zeros(1,lengthrun);
time = zeros(1,lengthrun);
PerSmallV = zeros(1,lengthrun);
AvTotalDelayV = zeros(1,lengthrun);
CongestionV = zeros(1,lengthrun);
PenaltyV = zeros(1,lengthrun);
PenaltyValueV = zeros(1,lengthrun);
```

```
RevenuesV = zeros(1,lengthrun);
RevenuesAll = zeros(TotalPortf,lengthrun);
UtilizationRatioV = zeros(1,lengthrun);
DepUtilizationRatioV = zeros(1,lengthrun);
ArrUtilizationRatioV = zeros(1,lengthrun);
LandingFeeSmallV = zeros(1,lengthrun);
LandingFeeMediumV = zeros(1,lengthrun);
TotalRunwayCapacityV = zeros(1,lengthrun);

if not(libisloaded('VenDLL32'))
    hfile = ['\\PINION-317\WorksInProgressWithoutSurrogate\vendll.h'];
    loadlibrary('VenDLL32',hfile)
end

rvalPtr1 = libpointer('singlePtr', NbofACV);
tvalPtr1 = libpointer('singlePtr', time);
rvalPtr2 = libpointer('singlePtr', PerSmallV);
rvalPtr5 = libpointer('singlePtr', AvTotalDelayV);
rvalPtr6 = libpointer('singlePtr', CongestionV);
rvalPtr7 = libpointer('singlePtr', PenaltyV);
rvalPtr8 = libpointer('singlePtr', RevenuesV);
rvalPtr4 = libpointer('singlePtr', LandingFeeSmallV);
rvalPtr16 = libpointer('singlePtr',TotalRunwayCapacityV);
rvalPtr17 = libpointer('singlePtr',PenaltyValueV);
rvalPtr14 = libpointer('singlePtr', LandingFeeMediumV);

%LOAD DATA FROM MACAD RUN

[AvTotalDelay] = xlsread('AllA1S2.xls','AverageTotalDelay','A1:O3500');
[NbAC] = xlsread('AllA1S2.xls','NbAC','A1:O3500');
[PerSmallAC] = xlsread('AllA1S2.xls','PerSmallAC','A1:O3500');
[TotArrCapacity] = xlsread('AllA1S2.xls','TotArrCapacity','A1:O3500');
[TotDepCapacity] = xlsread('AllA1S2.xls','TotDepCapacity','A1:O3500');
[AvArrDelays] = xlsread('AllA1S2.xls','ArrDelays','A1:O3500');
[AvDepDelays] = xlsread('AllA1S2.xls','DepDelays','A1:O3500');
[NbDep] = xlsread('AllA1S2.xls','NbDep','A1:O3500');
[NbArr] = xlsread('AllA1S2.xls','NbArr','A1:O3500');
[DepUtilizationRatio] = xlsread('AllA1S2.xls','DepUtilizationRatio','A1:O3500');
[ArrUtilizationRatio] = xlsread('AllA1S2.xls','ArrUtilizationRatio','A1:O3500');
[TotalAircraft] = xlsread('AllA1S2.xls','TotalAircraft','A1:O3500');
[TotalCapacity] = xlsread('AllA1S2.xls','TotalCapacity','A1:O3500');
```

```
[TotalUtilizationRatio] = xlsread('AllA1S2.xls','TotalUtilizationRatio','A1:O3500');
[AvRunwayCongDelay] = xlsread('AllA1S2.xls','AvRunwayCongDelay','A1:O3500');
[ArrCapacityperHour] = xlsread('AllA1S2.xls','ArrCapacityperHour','A1:O3500');
[DepCapacityperHour] = xlsread('AllA1S2.xls','DepCapacityperHour','A1:O3500');
[DepRunwayUtilizationRatio] = xlsread('AllA1S2.xls','DepRunwayUtilizationRatio','A1:O3500'
    );
[ArrRunwayUtilizationRatio] = xlsread('AllA1S2.xls','ArrRunwayUtilizationRatio','A1:O3500'
    );

%LOAD VENSIM MODEL

LoadModel(lengthrun); %Load the model and set the final time

str=['SIMULATE>RUNNAME|\\PINION-317\WorksInProgressWithoutSurrogate\Olive2'];

calllib('VenDLL32','vensim_be_quiet',2);
calllib('VenDLL32','vensim_command',str);

SetupGame(1);   %Set the game interval (every year)

%SET VENSIM MODEL INTO GAME MODE

game = ['MENU>GAME'];
lp4=libpointer('voidPtr',[int8(game) 0]);
r10 = calllib('VenDLL32','vensim_command',game);

%PASS VALUES TO VENSIM MODEL AND CONTINUE

for j = 1:1:TotalPortf
    AvTotalDelay(j,:);
    [RevenuesV] = Model2S234(lengthrun,AvTotalDelay(j,:),NbArr(j,:),PerSmallAC(j,:),
        ArrCapacityperHour(j,:),DepCapacityperHour(j,:),NbDep(j,:),TotDepCapacity(j,:),
        TotArrCapacity(j,:));
    RevenuesAll(j,:)= RevenuesV;
end

RevenuesAll
xlswrite('Airport1Scenario2Revenues.xls', [RevenuesAll],'Revenues'); %WORKS

result2 = ['GAME>ENDGAME'];
toc
```

F.6 ContinueGameOK.m

```
function ContinueGame()

gameon = ['GAME>GAMEON'];
lp5=libpointer('voidPtr',[int8(gameon) 0]);
calllib('VenDLL32','vensim_command',gameon);
```

F.7 CreatePortfolio5.m

```
function [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio5(TechID,
    TechInPlace,year)

%Connection to server and database
[dbConn] = ConnectToDB();

PortfolioT5 = {};

Portfolio1 = pick(TechID,1,''); %Portfolio of 1 technologies
Portfolio2 = pick(TechID,2,''); %Portfolio of 2 technologies
Portfolio3 = pick(TechID,3,'');  %Portfolio of 3 technologies
Portfolio4 = pick(TechID,4,''); %Portfolio of 4 technologies
Portfolio5 = pick(TechID,5,''); %Portfolio of 5 technologies
PortfolioT5 = {Portfolio1,Portfolio2,Portfolio3,Portfolio4,Portfolio5'}; %Group portfolios
     in 1 row

%Number of portfolios
TotRow = 0;
for k=1:length(TechID)-1
   [row column] = size(pick(TechID,k,''));
   TotRow = TotRow + row;
end
TotRow = TotRow + 1;  %Number of portfolios



SQLqueryMetric = ['select idMetrics from Metrics'];
AllMetricsID = fetch(dbConn, SQLqueryMetric);

Portfolio = pick(TechID,1,'');
[row1 column1] = size(Portfolio);
TechPortfolio = zeros(1,row1);
for k=1:1:row1
    TechPortfolio = Portfolio(k,:);
    for i=1:length(AllMetricsID)
        metricID = i-1;
        TotalImpact1(k,i) = TechCombinedImpact(metricID,TechPortfolio);
    end
```

```
end
FullTotalImpact1 = TotalImpact1;

Portfolio = pick(TechID,2,'');
[row2 column2] = size(Portfolio);
TechPortfolio = zeros(1,row2);
for k=1:1:row2
    TechPortfolio = Portfolio(k,:);
    for i=1:length(AllMetricsID)
        metricID = i-1;
        TotalImpact2(k,i) = TechCombinedImpact(metricID,TechPortfolio);
    end
end
FullTotalImpact2 = TotalImpact2;

Portfolio = pick(TechID,3,'');
[row3 column3] = size(Portfolio);
TechPortfolio = zeros(1,row3);
for k=1:1:row3
    TechPortfolio = Portfolio(k,:);
    for i=1:length(AllMetricsID)
        metricID = i-1;
        TotalImpact3(k,i) = TechCombinedImpact(metricID,TechPortfolio);
    end
end
FullTotalImpact3 = TotalImpact3;

Portfolio = pick(TechID,4,'');
[row4 column4] = size(Portfolio);
TechPortfolio = zeros(1,row4);
for k=1:1:row4
    TechPortfolio = Portfolio(k,:);
    for i=1:length(AllMetricsID)
        metricID = i-1;
        TotalImpact4(k,i) = TechCombinedImpact(metricID,TechPortfolio);
    end
end
FullTotalImpact4 = TotalImpact4;

Portfolio = pick(TechID,5,'')';
[row5 column5] = size(Portfolio);
```

```
TechPortfolio = zeros(1,row5);
for k=1:1:row5
    TechPortfolio = Portfolio(k,:);
    for i=1:length(AllMetricsID)
        metricID = i-1;
        TotalImpact5(k,i) = TechCombinedImpact(metricID,TechPortfolio);
    end
end
FullTotalImpact5 = TotalImpact5;

FullTotalImpact = [FullTotalImpact1;FullTotalImpact2;FullTotalImpact3;FullTotalImpact4;
    FullTotalImpact5]; %Row = portfolio, Column = Metric ; ROW =  rows of Portfolio1,
    Portfolio2, etc.) and column = length(AllMetricsID)

%UPDATE THE TECHS IN PLACE FOR EACH PORTFOLIO
TechInPlaceT5 = zeros(TotRow,length(TechInPlace)); %row = # of portfolio, length(
    TechInplace) = total # of techs
% Make sure that techs from previous portfolios are included
for i=1:TotRow
    for j=1:length(TechInPlace)
        TechInPlaceT5(i,j) = TechInPlace(j);
    end
end

if year == 2005
    techupd = 4;
end
if year == 2010
    techupd = 2;
end
if year == 2015
    techupd = 3;
end

%Update for each portfolio
for i=1:row1
    for j=1:column1
        TechInPlaceT5(i,1+Portfolio1{i,j}) = techupd;  %The first tech in the database as
            ID 0
    end
end
```

```
for i=1:row2
    for j=1:column2
        TechInPlaceT5(row1+i,1+Portfolio2{i,j}) = techupd;  %The first tech in the
            database as ID 0
    end
end
for i=1:row3
    for j=1:column3
        TechInPlaceT5(row1+row2+i,1+Portfolio3{i,j}) = techupd;  %The first tech in the
            database as ID 0
    end
end
for i=1:row4
    for j=1:column4
        TechInPlaceT5(row1+row2+row3+i,1+Portfolio4{i,j}) = techupd;  %The first tech in
            the database as ID 0
    end
end

for i=1:column5
    for j=1:row5
        TechInPlaceT5(row1+row2+row3+row4+1,1+Portfolio5{i,j}) = techupd;  %The first tech
             in the database as ID 0
    end
end
TechInPlaceT5;

end
```

F.8 InPlaceBaselineAirport2.m

```
function[TechInPlaceBaseline] = InPlaceBaselineAirport2()

%Connection to server and database
[dbConn] = ConnectToDB();

%Count the total number of technologies
SQLqueryAllTech = ['select Tech_ID  from Technologies'];
NbTech = fetch(dbConn, SQLqueryAllTech);

TechInPlaceBaseline = zeros(1,length(NbTech));

%Identify techs already in place
SQLqueryTechInplace = ['select Tech_ID from Technologies where Baseline2 = 2'];
TechID = fetch(dbConn, SQLqueryTechInplace);

for i=1:1:length(NbTech)
    for j=1:1:length(TechID)
        if NbTech{i} == TechID{j}
            TechInPlaceBaseline(i) = 1;
        end
    end
end

end
```

F.9 InPlaceBaseline.m

```
function[TechInPlaceBaseline] = InPlaceBaseline()

%Connection to server and database
[dbConn] = ConnectToDB();

%Count the total number of technologies
SQLqueryAllTech = ['select Tech_ID  from Technologies'];
NbTech = fetch(dbConn, SQLqueryAllTech);

TechInPlaceBaseline = zeros(1,length(NbTech));

%Identify techs already in place
SQLqueryTechInplace = ['select Tech_ID from Technologies where Baseline = 1'];
TechID = fetch(dbConn, SQLqueryTechInplace);

for i=1:1:length(NbTech)
    for j=1:1:length(TechID)
        if num2str(NbTech{i}) == num2str(TechID{j})
            TechInPlaceBaseline(i) = 1;
        end
    end
end

end
```

F.10 LoadModel.m

```
function LoadModel(FinalTime)

str=['SPECIAL>LOADMODEL|\\PINION-317\WorksInProgressWithoutSurrogate\
    ResearchSDModelDec2011.vpm'];
calllib('VenDLL32','vensim_be_quiet',0);
calllib('VenDLL32','vensim_command',str);

comstr3 = ['SIMULATE>SETVAL|FINAL TIME =', num2str(FinalTime)];
r3 = calllib('VenDLL32','vensim_command',comstr3);

end
```

F.11 Model.m

```
function Model(AvTotalDelay,NbArr,PerSmallAC,ArrCapacityperHour,DepCapacityperHour,NbDep,
    TotDepCapacity,TotArrCapacity)

comstr = ['SIMULATE>SETVAL|Number of arrivals = ', num2str(NbArr)];
calllib('VenDLL32','vensim_command',comstr);

comstr = ['SIMULATE>SETVAL|Percentage of small aircraft = ', num2str(PerSmallAC)];
calllib('VenDLL32','vensim_command',comstr);

comstr = ['SIMULATE>SETVAL|Average total delay per aircraft = ', num2str(AvTotalDelay)];
calllib('VenDLL32','vensim_command',comstr);

comstr = ['SIMULATE>SETVAL|Total arrival capacity = ', num2str(TotArrCapacity)];
calllib('VenDLL32','vensim_command',comstr);

comstr = ['SIMULATE>SETVAL|Total departure capacity = ', num2str(TotDepCapacity)];
calllib('VenDLL32','vensim_command',comstr);

comstr = ['SIMULATE>SETVAL|Runway arrival capacity = ', num2str(ArrCapacityperHour)];
calllib('VenDLL32','vensim_command',comstr);

comstr = ['SIMULATE>SETVAL|Runway departure capacity = ', num2str(DepCapacityperHour)];
calllib('VenDLL32','vensim_command',comstr);

comstr = ['SIMULATE>SETVAL|Number of departures = ', num2str(NbDep)];
calllib('VenDLL32','vensim_command',comstr);

 end
```

F.12 Model2S234.m

```
function [RevenuesV] = Model2S234(lengthrun,AvTotalDelay,NbArr,PerSmallAC,
    ArrCapacityperHour,DepCapacityperHour,NbDep,TotDepCapacity,TotArrCapacity)

TimebtwDecisions = 1; %years

time = zeros(1,lengthrun);

CongThreshold = 0.055;

% Init for Vensim value retrieval
RevenuesV = zeros(1,lengthrun);

if not(libisloaded('VenDLL32'))
    hfile = ['\\PINION-317\WorksInProgressWithoutSurrogate\vendll.h'];
    loadlibrary('VenDLL32',hfile)
end

tvalPtr1 = libpointer('singlePtr', time);
rvalPtr8 = libpointer('singlePtr', RevenuesV);

%LOAD VENSIM MODEL

LoadModel(lengthrun); %Load the model and set the final time

str=['SIMULATE>RUNNAME|\\PINION-317\WorksInProgressWithoutSurrogate\Olive2'];

calllib('VenDLL32','vensim_be_quiet',2);
calllib('VenDLL32','vensim_command',str);

SetupGame(1);   %Set the game interval (every year)

%SET VENSIM MODEL INTO GAME MODE

game = ['MENU>GAME'];
lp4=libpointer('voidPtr',[int8(game) 0]);
r10 = calllib('VenDLL32','vensim_command',game);
```

```
%PASS VALUES TO VENSIM MODEL AND CONTINUE

for i=1:1:lengthrun
    Model(AvTotalDelay(i),NbArr(i),PerSmallAC(i),ArrCapacityperHour(i),DepCapacityperHour(
        i),NbDep(i),TotDepCapacity(i),TotArrCapacity(i));
    ContinueGame();
end

%RETRIEVE DATA

tpoints1 = calllib('VenDLL32','vensim_get_data','Olive2.vdf','Airport revenues','time',
    rvalPtr8(1),tvalPtr1(1),lengthrun);
RevenuesV = rvalPtr8(1).Value;
result2 = ['GAME>ENDGAME'];

end
```

F.13 pick.m

```
% pick    Picking elements from a set (combinations, permutations)
%
%   s = pick(V,k,Type)
%
%   Gives all possibilities of picking k elements from the
%   set V with or without order and repetition. V can be an
%   array of any size and any type.
%
%   Type can have the following values: '', 'o', 'r', 'or'.
%     'o' means pick ordered set of k elements
%     'r' means replace elements after picking
%
%   s is an array with all picks, one subset per row.
%
%   Examples
%     pick(1:2,5,'or')
%     pick('abcd',2,'')
%     pick(-1:1,4,'r')
%     pick('X':'Z',3,'o')

% Stefan Stoll, ETH Zurich, 20 October 2006

function s = pick(V,k,Type)

errThirdMissing = 'Third argument Type ('''', ''o'', ''r'', or ''or'') is missing!';
errThreeExpected = 'Three arguments (V, k, Type) must be provided.';

switch nargin
  case 3,
  case 2, error(errThirdMissing);
  case 1,
    if strcmp(V,'test');
      pick_test;
      return;
    else
      error(errThreeExpected);
    end
```

```
  case 0, help(mfilename); return;
  otherwise, error(errThreeExpected);
end

N = numel(V);

if (N==0)
  error('First argument V must be an array with at least one element.');
end

if (numel(k)≠1) || rem(k,1) || (k<1)
  k
  error('Second argument k must be a positive integer. You gave the above.');
end

if ¬ischar(Type)
  Type
  error('Third argument must be a string.');
end

if isempty(strfind(Type,'r')) && (k>N)
  str = sprintf('Picking elements without repetition:\n  k must not be larger than the
      number of elements in V.\n');
  error([str 'You gave k=%d for %d elements in V.'],k,N);
end

switch sort(Type)
  case '',   idx = combinations_without_repetition(N,k);
  case 'o',  idx = permutations_without_repetition(N,k);
  case 'r',  idx = combinations_with_repetition(N,k);
  case 'or', idx = permutations_with_repetition(N,k);
  otherwise
    Type
    error('Third argument Type must be one of '''', ''o'', ''r'', ''or''.');
end

s = V(idx);
if (k==1), s = s(:); end

return
```

```
%=====================================================================
function m = combinations_with_repetition(N,k)

if (k==1), m = (1:N).'; return; end
if (N==1), m = ones(1,k); return; end

m = [];
for q = 1:N
  mnext = combinations_with_repetition(N+1-q,k-1);
  m = [m; q*ones(size(mnext,1),1), mnext+q-1];
end



%===================================================================
function p = permutations_without_repetition(N,k)

p = permutations_with_repetition(N,k);
ps = sort(p.').';
idx = any(ps(:,2:end)==ps(:,1:end-1),2);
p(idx,:) = [];



%===================================================================
function s = permutations_with_repetition(N,k)

if (k==1), s = (1:N).'; return; end
if (N==1), s = ones(1,k); return; end

[idx{1:k}] = ndgrid(1:N);
s = fliplr(reshape(cat(ndims(idx{1}),idx{:}),[],k));



%===================================================================
function c = combinations_without_repetition(N,k)

if (N>1)
  c = nchoosek(1:N,k);
else
  c = 1;
end
```

```
%==================================================================
function pick_test

disp('=========== pick() tests ======================');

Nmax = 6;

Type = {'','o','r','or'};
Name{1} = 'Combinations without repetition';
Name{2} = 'Permutations without repetition';
Name{3} = 'Combinations with repetition';
Name{4} = 'Permutations with repetition';
Repetition = [0 0 1 1];

for t = 1:4
  disp(' ');
  disp(Name{t});
  for N = 1:Nmax
    if Repetition(t), kmax = Nmax; else kmax = N; end
    for k = 1:kmax
      s = pick(uint8(1:N),k,Type{t});
      m1 = size(s,1); k1 = size(s,2);
      switch t
        case 1, m = nchoosek(N,k);
        case 2, m = prod(N-k+1:N);
        case 3, m = nchoosek(N+k-1,k);
        case 4, m = N^k;
      end
      fprintf('  N=%d, k=%d, expected %dx%d, found %dx%d\n',N,k,m,k,m1,k1);
      if (m1≠m) | (k1≠k)
        error('Unexpected size of output array!');
      end
    end
  end
end
disp('All tests passed!');
```

F.14 PortfolioBasisAirport2.m

```
function [TechforPortfolio] = PortfolioBasisAirport2(TechInPlace,year)

%This function identified technologyies to be included in a portfolio based on
%the year of deployment and their relationship(s) with other technologies

%Connection to server and database
[dbConn] = ConnectToDB();

%Choose all technologies that have an implementation date less or equal
%than 'year' and that belong in the set of techs picked as a proof of
%concept for the research
SQLqueryTech = ['select Tech_ID from Technologies where ImplDate ≤' , year,' and POC2 = 1'
    ];
TechID = fetch(dbConn, SQLqueryTech);
TechID;

SQLqueryAllTech = ['select Tech_ID from Technologies'];
AllTechID = fetch(dbConn, SQLqueryAllTech);
IndexTobeRemoved = zeros(length(TechID));
k = 0;
for i=1:1:length(TechID)
    k = k+1;
    for j=1:1:length(AllTechID)
        inTechConsidered = 1;
        SQLquerymij = ['select mij from BinaryMatrix where Techi =',num2str(TechID{i}),'
            and Techj =',num2str(AllTechID{j})];
        mij = fetch(dbConn,SQLquerymij);
        SQLquerymji = ['select mij from BinaryMatrix where Techi =',num2str(AllTechID{j}),
            ' and Techj =',num2str(TechID{i})];
        mji = fetch(dbConn,SQLquerymji);
        if (length(cell2mat(mij)) ≠ 0 && isempty(mji))
            %Check if the technology needed is already in place or not
            if (TechInPlace(j) == 0) %if not in place then check if that technology is in
                the list of technologies considered
                if ismember(cell2mat(AllTechID(j)),cell2mat(TechID)) == 0
                    inTechConsidered = 0;
                else
```

```
                    inTechConsidered = 1;
                end
                if inTechConsidered == 0 %Technology needed not in list of techs
                    considered
                    %store indices of techs to be removed from TechID
                    IndexTobeRemoved(k) = i;
                end
            end
        end
    end
end

for p=length(TechID):-1:1
    if IndexTobeRemoved(p) ≠ 0
        TechID(IndexTobeRemoved(p)) = [];
    end

end

TechforPortfolio = TechID;

end
```

F.15 PortfolioBasis.m

```
function [TechforPortfolio] = PortfolioBasis(TechInPlace,year)

%This function identified technologyies to be included in a portfolio based on
%the year of deployment and their relationship(s) with other technologies

%Connection to server and database
[dbConn] = ConnectToDB();

%Choose all technologies that have an implementation date less or equal
%than 'year' and that belong in the set of techs picked as a proof of
%concept for the research
SQLqueryTech = ['select Tech_ID from Technologies where ImplDate ≤' , year,' and POC = 1'
    ];
TechID = fetch(dbConn, SQLqueryTech)
TechID;

SQLqueryAllTech = ['select Tech_ID from Technologies'];
AllTechID = fetch(dbConn, SQLqueryAllTech);
IndexTobeRemoved = zeros(length(TechID));
k = 0;
for i=1:1:length(TechID)
    k = k+1;
    for j=1:1:length(AllTechID)
        inTechConsidered = 1;
        SQLquerymij = ['select mij from BinaryMatrix where Techi =',num2str(TechID{i}),'
            and Techj =',num2str(AllTechID{j})];
        mij = fetch(dbConn,SQLquerymij);
        SQLquerymji = ['select mij from BinaryMatrix where Techi =',num2str(AllTechID{j}),
            ' and Techj =',num2str(TechID{i})];
        mji = fetch(dbConn,SQLquerymji);
        if (length(cell2mat(mij)) ≠ 0 && isempty(mji))
            %Check if the technology needed is already in place or not
            if (TechInPlace(j) == 0) %if not in place then check if that technology is in
                the list of technologies considered
                for p=1:1:length(TechID)
                    cell2mat(TechID(p));
                    if cell2mat(TechID(p)) == cell2mat(TechID(j))
```

```
                        inTechConsidered = 1;
                    else
                        inTechConsidered = 0;
                    end
                end
                if inTechConsidered == 0 %Technology needed not in list of techs
                    considered
                    %store indices of techs to be removed from TechID
                    IndexTobeRemoved(k) = i;
                end
            end
        end
    end
end

for p=length(TechID):-1:1
    if IndexTobeRemoved(p) ≠ 0
        TechID(IndexTobeRemoved(p)) = [];
    end
end

TechforPortfolio = TechID;

end
```

F.16 PortfolioImpactAirport2.m

```
function [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = PortfolioImpactAirport2(
    year,TechInPlace)

%Obtain technologies that form the basis for the portfolios
[TechID] = PortfolioBasisAirport2(TechInPlace,num2str(year));

if length(TechID) == 1
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio1(TechID,
        TechInPlace,year);
end
if length(TechID) == 2
    [TotRow PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio2(TechID,
        TechInPlace,year);
end
if length(TechID) == 3
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio3(TechID,
        TechInPlace,year);
end
if length(TechID) == 4
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio4(TechID,
        TechInPlace,year);
end
if length(TechID) == 5
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio5(TechID,
        TechInPlace,year);
end
if length(TechID) == 6
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio6(TechID,
        TechInPlace,year);
end
if length(TechID) == 7
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio7(TechID,
        TechInPlace,year);
end
if length(TechID) == 8
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio8(TechID,
        TechInPlace,year);
```

```
end
if length(TechID) == 9
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio9(TechID,
        TechInPlace,year);
end
if length(TechID) == 10
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio10(TechID,
        TechInPlace,year);
end


end
```

F.17 PortfolioImpact.m

```
function [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = PortfolioImpact(year,
    TechInPlace)

%Obtain technologies that form the basis for the portfolios
[TechID] = PortfolioBasis(TechInPlace,num2str(year));

if length(TechID) == 1
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio1(TechID,
        TechInPlace,year);
end
if length(TechID) == 2
    [TotRow PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio2(TechID,
        TechInPlace,year);
end
if length(TechID) == 3
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio3(TechID,
        TechInPlace,year);
end
if length(TechID) == 4
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio4(TechID,
        TechInPlace,year);
end
if length(TechID) == 5
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio5(TechID,
        TechInPlace,year);
end
if length(TechID) == 6
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio6(TechID,
        TechInPlace,year);
end
if length(TechID) == 7
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio7(TechID,
        TechInPlace,year);
end
if length(TechID) == 8
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio8(TechID,
        TechInPlace,year);
```

```
end
if length(TechID) == 9
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio9(TechID,
        TechInPlace,year);
end
if length(TechID) == 10
    [TotRow, PortfolioT5, FullTotalImpact, TechInPlaceT5] = CreatePortfolio10(TechID,
        TechInPlace,year);
end

end
```

F.18 RunT5Airport2.m

```
function[AverageofAverageTotalDelayS2, AverageofArrUtilizationRatioS2,
    AverageofDepUtilizationRatioS2, AverageofTotalAircraftS2, AverageofTotalCapacityS2,
    AverageofTotalUtilizationRatioS2, AverageofDepRunwayUtilizationRatioS2,
    AverageofArrRunwayUtilizationRatioS2, AverageofNbDepS2, AverageofNbArrS2,
    AverageofPerSmallACS2, AverageofNbACS2, AverageofTotArrCapacityS2,
    AverageofTotDepCapacityS2, AverageofArrDelaysS2, AverageofDepDelaysS2,
    AverageofAvRunwayCongDelayS2, AverageofDepCapacityperHourS2,
    AverageofArrCapacityperHourS2]=RunT5Airport2(MaxAC,MaxPerc,k,NewImpact,NbPortfolios,
    Portfolio)

TimebtwDecisions =15; %years
lengthrun = 15; %years
TotalNbofArrACInitial = MaxAC;
PerSMALLacArrInitial  = MaxPerc;
time = zeros(1,TimebtwDecisions);
TotalNbofArrAC = zeros(1,TimebtwDecisions);
AvTotalDelay = zeros(1,TimebtwDecisions);
NbAC = zeros(1,TimebtwDecisions);
PerSmallAC = zeros(1,TimebtwDecisions);
TotArrCapacity = zeros(1,TimebtwDecisions);
TotDepCapacity =  zeros(1,TimebtwDecisions);
AvArrDelays =  zeros(1,TimebtwDecisions);
AvDepDelays = zeros(1,TimebtwDecisions);
NbDep = zeros(1,TimebtwDecisions);
NbArr = zeros(1,TimebtwDecisions);
DepUtilizationRatio = zeros(1,TimebtwDecisions);
ArrUtilizationRatio = zeros(1,TimebtwDecisions);
UtilizationRatio = zeros(1,TimebtwDecisions);
TotalAircraft = zeros(1,TimebtwDecisions);
TotalCapacity = zeros(1,TimebtwDecisions);
TotalUtilizationRatio = zeros(1,TimebtwDecisions);
AvRunwayCongDelay = zeros(1,TimebtwDecisions);
ArrCapacityperHour = zeros(1,TimebtwDecisions);
DepCapacityperHour = zeros(1,TimebtwDecisions);
DepRunwayUtilizationRatio = zeros(1,TimebtwDecisions);
ArrRunwayUtilizationRatio = zeros(1,TimebtwDecisions);
```

```
CongThreshold = 0.055;
p = 0;

%INTERACT WITH MACAD MODEL

[HBGrowthRate HBFleetMix LBGrowthRate LBFleetMix] = Traffic();

%To initialize COM client

mc = actxserver('ModelCenter.Application');

for l=1:length(Portfolio)
    M = cell2mat(Portfolio{1,l});
    [i,j] = size(M);
    for n=1:i
        p = p + 1;
        if (k==p)
            M(n,:);
            if ismember(8,M(n,:))
                invoke(mc,'loadModel','C:\Users\opinon\Documents\
                    WorksInProgressWithoutSurrogate\MACAD2SoloDec2011.pxc');
            else

                %If there is no lighting system, then aircraft do not land
                %after dark, which reduces the traffic at the airport
                invoke(mc,'loadModel','C:\Users\opinon\Documents\
                    WorksInProgressWithoutSurrogate\MACAD2SoloDec2011Airport2.pxc');
            end
        end
    end
end

%Assign Tech values to the model

invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ApproachSpeedSMALLAC', NewImpact(k,1));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ApproachSpeedMEDIUMAC', NewImpact(k,2));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrRunwayOccTimeforSMALLacinsec',
    NewImpact(k,3));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrRunwayOccTimeforMEDIUMacinsec',
    NewImpact(k,4));
```

```
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepRunwayOccTimeforSMALLacinsec',
    NewImpact(k,5));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepRunwayOccTimeforMEDIUMacinsec',
    NewImpact(k,6));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrivalsTaxiAverage', NewImpact(k,7));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepTaxiAverage', NewImpact(k,8));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACSMALLFollowSMALL',
    NewImpact(k,9));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACSMALLFollowMEDIUM',
    NewImpact(k,10));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACMEDIUMFollowSMALL' ,
    NewImpact(k,11));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACMEDIUMFollowMEDIUM',
    NewImpact(k,12));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepSMALLFollowSMALL', NewImpact
    (k,13));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepSMALLFollowMEDIUM',
    NewImpact(k,14));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepMEDIUMFollowSMALL',
    NewImpact(k,15));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepMEDIUMFollowMEDIUM',
    NewImpact(k,16));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinArrDepSeparation', NewImpact(k,17));



TotalNbRuns = 500;


AllAvTotDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllArrUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllDepUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalAircraft = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllDepRunwayUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllArrRunwayUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllNbDep = zeros(TotalNbRuns,TimebtwDecisions);
AllNbArr = zeros(TotalNbRuns,TimebtwDecisions);
AllPerSmallAC = zeros(TotalNbRuns,TimebtwDecisions);
AllNbAC = zeros(TotalNbRuns,TimebtwDecisions);
AllTotArrCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllTotDepCapacity = zeros(TotalNbRuns,TimebtwDecisions);
```

```
AllAvArrDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllAvDepDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllAvRunwayCongDelay = zeros(TotalNbRuns,TimebtwDecisions);
AllDepCapacityperHour = zeros(TotalNbRuns,TimebtwDecisions);
AllArrCapacityperHour = zeros(TotalNbRuns,TimebtwDecisions);


AverageofAverageTotalDelayS2 = zeros(1,TimebtwDecisions);
AverageofArrUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofDepUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofTotalAircraftS2 = zeros(1,TimebtwDecisions);
AverageofTotalCapacityS2 = zeros(1,TimebtwDecisions);
AverageofTotalUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofDepRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofArrRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofNbDepS2 = zeros(1,TimebtwDecisions);
AverageofNbArrS2 = zeros(1,TimebtwDecisions);
AverageofPerSmallACS2 = zeros(1,TimebtwDecisions);
AverageofNbACS2 = zeros(1,TimebtwDecisions);
AverageofTotArrCapacityS2 =  zeros(1,TimebtwDecisions);
AverageofTotDepCapacityS2 =  zeros(1,TimebtwDecisions);
AverageofArrDelaysS2 =  zeros(1,TimebtwDecisions);
AverageofDepDelaysS2 =  zeros(1,TimebtwDecisions);
AverageofAvRunwayCongDelayS2 = zeros(1,TimebtwDecisions);
AverageofDepCapacityperHourS2 = zeros(1,TimebtwDecisions);
AverageofArrCapacityperHourS2 = zeros(1,TimebtwDecisions);

for run = 1:TotalNbRuns

    TotalNbofArrACInitial = MaxAC;
    PerSMALLacArrInitial  = MaxPerc;

    for i=1:1:10

        GRrandom = str2double(LBGrowthRate{1}) + rand(1,1) * (str2double(HBGrowthRate{1})
            - str2double(LBGrowthRate{1}));  %Uniform distribution between the bound set
            in database
        FMrandom = str2double(LBFleetMix{1}) + rand(1,1) * (str2double(HBFleetMix{1}) -
            str2double(LBFleetMix{1})); %Uniform distribution between the bound set in
            database
```

```
TotalNbofArrAC(i) =  TotalNbofArrACInitial + TotalNbofArrACInitial * GRrandom/100;
PerSMALLacArr(i) =  PerSMALLacArrInitial +  PerSMALLacArrInitial * FMrandom/100;

%Assign values to traffic inputs

invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.TotalNbofArrAC',TotalNbofArrAC(i))
    ;
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.PerSMALLacArr',PerSMALLacArr(i));

TotalNbofArrACInitial = TotalNbofArrAC(i);
PerSMALLacArrInitial = PerSMALLacArr(i);

%Run MACAD and retrieve outputs of interest

NbAC(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.TotalNbofArrAC');
PerSmallAC(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.PerSMALLacArr');
AvTotalDelay(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvTotalDelays');
TotArrCapacity(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.TotArrCapacity
    ');
TotDepCapacity(i) =  invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
    TotDepCapacity');
AvArrDelays(i) =  invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvArrDelays');
AvDepDelays(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvDepDelay');
AvRunwayCongDelay(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
    AvRunwayCongDelay');
NbDep(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.NbDep');
NbArr(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.NbArrivals');
ArrCapacityperHour(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
    ArrivalCapacityperHourEvenMix');
DepCapacityperHour(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
    DepartureCapacityperHourEvenMix');

% Calculate utilizatio ratios
DepUtilizationRatio(i) = NbDep(i)/ TotDepCapacity(i);
ArrUtilizationRatio(i) = NbArr(i)/TotArrCapacity(i);
DepRunwayUtilizationRatio(i) = NbDep(i) / (DepCapacityperHour(i) * 18);
ArrRunwayUtilizationRatio(i) = NbArr(i) / (ArrCapacityperHour(i) * 18);
TotalAircraft(i) = NbDep(i)+ NbArr(i);
TotalCapacity(i) = TotDepCapacity(i)+TotArrCapacity(i);
TotalUtilizationRatio(i) = TotalAircraft(i)/TotalCapacity(i);
```

```
end

AllAvTotDelays(run,:) = AvTotalDelay;
AllArrUtilizationRatio(run,:) = ArrUtilizationRatio;
AllDepUtilizationRatio(run,:) = DepUtilizationRatio;
AllDepRunwayUtilizationRatio(run,:) = DepRunwayUtilizationRatio;
AllArrRunwayUtilizationRatio(run,:) = ArrRunwayUtilizationRatio;
AllTotalAircraft(run,:) = TotalAircraft;
AllTotalCapacity(run,:) = TotalCapacity;
AllTotalUtilizationRatio(run,:) = TotalUtilizationRatio;
AllNbDep(run,:) = NbDep;
AllNbArr(run,:) = NbArr;
AllPerSmallAC(run,:) = PerSmallAC;
AllNbAC(run,:) = NbAC;
AllTotArrCapacity(run,:) = TotArrCapacity;
AllTotDepCapacity(run,:) = TotDepCapacity;
AllAvArrDelays(run,:) = AvArrDelays;
AllAvDepDelays(run,:) = AvDepDelays;
AllAvRunwayCongDelay(run,:) = AvRunwayCongDelay;
AllDepCapacityperHour(run,:) = DepCapacityperHour;
AllArrCapacityperHour(run,:) = ArrCapacityperHour;

%Save data in Excel spreadsheet

SaveAllRunsS2Airport2withTech(k,AllAvTotDelays,AllArrUtilizationRatio,
    AllDepUtilizationRatio,AllTotalAircraft,AllTotalCapacity,AllTotalUtilizationRatio,
    AllDepRunwayUtilizationRatio,AllArrRunwayUtilizationRatio,AllNbDep,AllNbArr,
    AllPerSmallAC,AllNbAC,AllTotArrCapacity,AllTotDepCapacity,AllAvArrDelays,
    AllAvDepDelays,AllAvRunwayCongDelay,AllDepCapacityperHour,AllArrCapacityperHour);

AverageofAverageTotalDelayS2 = AverageofAverageTotalDelayS2 + AllAvTotDelays(run,:);
AverageofArrUtilizationRatioS2 = AverageofArrUtilizationRatioS2 +
    AllArrUtilizationRatio(run,:);
AverageofDepUtilizationRatioS2 = AverageofDepUtilizationRatioS2 +
    AllDepUtilizationRatio(run,:);
AverageofTotalAircraftS2 = AverageofTotalAircraftS2 +  AllTotalAircraft(run,:);
AverageofTotalCapacityS2 = AverageofTotalCapacityS2 +  AllTotalCapacity(run,:);
AverageofTotalUtilizationRatioS2 = AverageofTotalUtilizationRatioS2 +
    AllTotalUtilizationRatio(run,:);
AverageofDepRunwayUtilizationRatioS2 = AverageofDepRunwayUtilizationRatioS2 +
    AllDepRunwayUtilizationRatio(run,:);
```

```
    AverageofArrRunwayUtilizationRatioS2 = AverageofArrRunwayUtilizationRatioS2 +
        AllArrRunwayUtilizationRatio(run,:);
    AverageofNbDepS2 = AverageofNbDepS2 + AllNbDep(run,:);
    AverageofNbArrS2 = AverageofNbArrS2  + AllNbArr(run,:);
    AverageofPerSmallACS2 = AverageofPerSmallACS2 + AllPerSmallAC(run,:);
    AverageofNbACS2 = AverageofNbACS2 + AllNbAC(run,:);
    AverageofTotArrCapacityS2 =  AverageofTotArrCapacityS2 + AllTotArrCapacity(run,:);
    AverageofTotDepCapacityS2 =  AverageofTotDepCapacityS2 + AllTotDepCapacity(run,:);
    AverageofArrDelaysS2 =  AverageofArrDelaysS2 + AllAvArrDelays(run,:);
    AverageofDepDelaysS2 =  AverageofDepDelaysS2 + AllAvDepDelays(run,:);
    AverageofAvRunwayCongDelayS2 = AverageofAvRunwayCongDelayS2 + AllAvRunwayCongDelay(run
        ,:);
    AverageofDepCapacityperHourS2 = AverageofDepCapacityperHourS2 + AllDepCapacityperHour(
        run,:);
    AverageofArrCapacityperHourS2 = AverageofArrCapacityperHourS2 + AllArrCapacityperHour(
        run,:);

    run = run+1;

end

AverageofAverageTotalDelayS2 = AverageofAverageTotalDelayS2/TotalNbRuns;
AverageofArrUtilizationRatioS2 = AverageofArrUtilizationRatioS2/TotalNbRuns;
AverageofDepUtilizationRatioS2 = AverageofDepUtilizationRatioS2/TotalNbRuns;
AverageofTotalAircraftS2  = AverageofTotalAircraftS2/TotalNbRuns;
AverageofTotalCapacityS2 = AverageofTotalCapacityS2/TotalNbRuns;
AverageofTotalUtilizationRatioS2 = AverageofTotalUtilizationRatioS2/TotalNbRuns;
AverageofDepRunwayUtilizationRatioS2 = AverageofDepRunwayUtilizationRatioS2/TotalNbRuns;
AverageofArrRunwayUtilizationRatioS2 = AverageofArrRunwayUtilizationRatioS2/TotalNbRuns;
AverageofNbDepS2 = AverageofNbDepS2/TotalNbRuns;
AverageofNbArrS2 = AverageofNbArrS2/TotalNbRuns;
AverageofPerSmallACS2 = AverageofPerSmallACS2/TotalNbRuns;
AverageofNbACS2 = AverageofNbACS2/TotalNbRuns;
AverageofTotArrCapacityS2 = AverageofTotArrCapacityS2/TotalNbRuns;
AverageofTotDepCapacityS2 = AverageofTotDepCapacityS2/TotalNbRuns;
AverageofArrDelaysS2 = AverageofArrDelaysS2/TotalNbRuns;
AverageofDepDelaysS2 = AverageofDepDelaysS2/TotalNbRuns;
AverageofAvRunwayCongDelayS2 = AverageofAvRunwayCongDelayS2/TotalNbRuns;
AverageofDepCapacityperHourS2 = AverageofDepCapacityperHourS2/TotalNbRuns;
AverageofArrCapacityperHourS2 = AverageofArrCapacityperHourS2/TotalNbRuns;
```

```
%Save data in Excel spreadsheet

xlswrite('5yearswithnoTechS2.xls', [AverageofAverageTotalDelay],'AverageTotalDelay');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrUtilizationRatio],'ArrUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepUtilizationRatio],'DepUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotalAircraft],'TotalAircraft');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotalCapacity],'TotalCapacity');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotalUtilizationRatio],'TotalUtilizationRatio
    ');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepRunwayUtilizationRatio],'
    DepRunwayUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrRunwayUtilizationRatio],'
    ArrRunwayUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofNbDep],'NbDep');
xlswrite('5yearswithnoTechS2.xls', [AverageofNbArr],'NbArr');
xlswrite('5yearswithnoTechS2.xls', [AverageofPerSmallAC],'PerSmallAC');
xlswrite('5yearswithnoTechS2.xls', [AverageofNbAC],'NbAC');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotArrCapacity],'TotArrCapacity');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotDepCapacity],'TotDepCapacity');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrDelays],'ArrDelays');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepDelays],'DepDelays');
xlswrite('5yearswithnoTechS2.xls', [AverageofAvRunwayCongDelay],'AvRunwayCongDelay');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepCapacityperHour],'DepCapacityperHour');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrCapacityperHour],'CapacityperHour');

end
```

F.19 RunT5.m

```
function[AverageofAverageTotalDelayS2, AverageofArrUtilizationRatioS2,
    AverageofDepUtilizationRatioS2, AverageofTotalAircraftS2, AverageofTotalCapacityS2,
    AverageofTotalUtilizationRatioS2, AverageofDepRunwayUtilizationRatioS2,
    AverageofArrRunwayUtilizationRatioS2, AverageofNbDepS2, AverageofNbArrS2,
    AverageofPerSmallACS2, AverageofNbACS2, AverageofTotArrCapacityS2,
    AverageofTotDepCapacityS2, AverageofArrDelaysS2, AverageofDepDelaysS2,
    AverageofAvRunwayCongDelayS2, AverageofDepCapacityperHourS2,
    AverageofArrCapacityperHourS2]=RunT5(MaxAC,MaxPerc,k,NewImpact,NbPortfolios)


TimebtwDecisions =15; %years
lengthrun = 15; %years
TotalNbofArrACInitial = MaxAC;
PerSMALLacArrInitial  = MaxPerc;
time = zeros(1,TimebtwDecisions);
TotalNbofArrAC = zeros(1,TimebtwDecisions);
AvTotalDelay = zeros(1,TimebtwDecisions);
NbAC = zeros(1,TimebtwDecisions);
PerSmallAC = zeros(1,TimebtwDecisions);
TotArrCapacity = zeros(1,TimebtwDecisions);
TotDepCapacity =  zeros(1,TimebtwDecisions);
AvArrDelays =  zeros(1,TimebtwDecisions);
AvDepDelays = zeros(1,TimebtwDecisions);
NbDep = zeros(1,TimebtwDecisions);
NbArr = zeros(1,TimebtwDecisions);
DepUtilizationRatio = zeros(1,TimebtwDecisions);
ArrUtilizationRatio = zeros(1,TimebtwDecisions);
UtilizationRatio = zeros(1,TimebtwDecisions);
TotalAircraft = zeros(1,TimebtwDecisions);
TotalCapacity = zeros(1,TimebtwDecisions);
TotalUtilizationRatio = zeros(1,TimebtwDecisions);
AvRunwayCongDelay = zeros(1,TimebtwDecisions);
ArrCapacityperHour = zeros(1,TimebtwDecisions);
DepCapacityperHour = zeros(1,TimebtwDecisions);
DepRunwayUtilizationRatio = zeros(1,TimebtwDecisions);
ArrRunwayUtilizationRatio = zeros(1,TimebtwDecisions);
```

```
CongThreshold = 0.055;

%INTERACT WITH MACAD MODEL

[HBGrowthRate HBFleetMix LBGrowthRate LBFleetMix] = Traffic();

%To initialize COM client

mc = actxserver('ModelCenter.Application');

%To load MACAD model

invoke(mc,'loadModel','C:\Documents and Settings\opinon\My Documents\MatlabResearch\
    WorksInProgressWithoutSurrogate\MACAD2SoloDec2011.pxc');

%Assign Tech values to the model

invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ApproachSpeedSMALLAC', NewImpact(k,1));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ApproachSpeedMEDIUMAC', NewImpact(k,2));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrRunwayOccTimeforSMALLacinsec',
    NewImpact(k,3));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrRunwayOccTimeforMEDIUMacinsec',
    NewImpact(k,4));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepRunwayOccTimeforSMALLacinsec',
    NewImpact(k,5));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepRunwayOccTimeforMEDIUMacinsec',
    NewImpact(k,6));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrivalsTaxiAverage', NewImpact(k,7));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepTaxiAverage', NewImpact(k,8));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACSMALLFollowSMALL',
    NewImpact(k,9));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACSMALLFollowMEDIUM',
    NewImpact(k,10));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACMEDIUMFollowSMALL' ,
    NewImpact(k,11));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACMEDIUMFollowMEDIUM',
    NewImpact(k,12));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepSMALLFollowSMALL', NewImpact
    (k,13));
```

```
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepSMALLFollowMEDIUM',
    NewImpact(k,14));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepMEDIUMFollowSMALL',
    NewImpact(k,15));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepMEDIUMFollowMEDIUM',
    NewImpact(k,16));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinArrDepSeparation', NewImpact(k,17));

TotalNbRuns = 500;

AllAvTotDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllArrUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllDepUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalAircraft = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllDepRunwayUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllArrRunwayUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllNbDep = zeros(TotalNbRuns,TimebtwDecisions);
AllNbArr = zeros(TotalNbRuns,TimebtwDecisions);
AllPerSmallAC = zeros(TotalNbRuns,TimebtwDecisions);
AllNbAC = zeros(TotalNbRuns,TimebtwDecisions);
AllTotArrCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllTotDepCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllAvArrDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllAvDepDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllAvRunwayCongDelay = zeros(TotalNbRuns,TimebtwDecisions);
AllDepCapacityperHour = zeros(TotalNbRuns,TimebtwDecisions);
AllArrCapacityperHour = zeros(TotalNbRuns,TimebtwDecisions);

AverageofAverageTotalDelayS2 = zeros(1,TimebtwDecisions);
AverageofArrUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofDepUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofTotalAircraftS2 = zeros(1,TimebtwDecisions);
AverageofTotalCapacityS2 = zeros(1,TimebtwDecisions);
AverageofTotalUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofDepRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofArrRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofNbDepS2 = zeros(1,TimebtwDecisions);
AverageofNbArrS2 = zeros(1,TimebtwDecisions);
AverageofPerSmallACS2 = zeros(1,TimebtwDecisions);
```

```
AverageofNbACS2 = zeros(1,TimebtwDecisions);
AverageofTotArrCapacityS2 =  zeros(1,TimebtwDecisions);
AverageofTotDepCapacityS2 =  zeros(1,TimebtwDecisions);
AverageofArrDelaysS2 =  zeros(1,TimebtwDecisions);
AverageofDepDelaysS2 =  zeros(1,TimebtwDecisions);
AverageofAvRunwayCongDelayS2 = zeros(1,TimebtwDecisions);
AverageofDepCapacityperHourS2 = zeros(1,TimebtwDecisions);
AverageofArrCapacityperHourS2 = zeros(1,TimebtwDecisions);


for run = 1:TotalNbRuns

    TotalNbofArrACInitial = MaxAC;
    PerSMALLacArrInitial  = MaxPerc;

    for i=1:1:10

        GRrandom = str2double(LBGrowthRate{1}) + rand(1,1) * (str2double(HBGrowthRate{1}) - str2double(LBGrowthRate{1}));  %Uniform distribution between the bound set in database
        FMrandom = str2double(LBFleetMix{1}) + rand(1,1) * (str2double(HBFleetMix{1}) - str2double(LBFleetMix{1})); %Uniform distribution between the bound set in database

        TotalNbofArrAC(i) =  TotalNbofArrACInitial + TotalNbofArrACInitial * GRrandom/100;
        PerSMALLacArr(i) =  PerSMALLacArrInitial +  PerSMALLacArrInitial * FMrandom/100;

        %Assign values to traffic inputs

        invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.TotalNbofArrAC',TotalNbofArrAC(i));
        invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.PerSMALLacArr',PerSMALLacArr(i));

        TotalNbofArrACInitial = TotalNbofArrAC(i);
        PerSMALLacArrInitial = PerSMALLacArr(i);

        %Run MACAD and retrieve outputs of interest

        NbAC(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.TotalNbofArrAC');
        PerSmallAC(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.PerSMALLacArr');
        AvTotalDelay(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvTotalDelays');
```

```
    TotArrCapacity(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.TotArrCapacity
        ');
    TotDepCapacity(i) =  invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        TotDepCapacity');
    AvArrDelays(i) =  invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvArrDelays');
    AvDepDelays(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvDepDelay');
    AvRunwayCongDelay(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        AvRunwayCongDelay');
    NbDep(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.NbDep');
    NbArr(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.NbArrivals');
    ArrCapacityperHour(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        ArrivalCapacityperHourEvenMix');
    DepCapacityperHour(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        DepartureCapacityperHourEvenMix');

    % Calculate utilizatio ratios
    DepUtilizationRatio(i) = NbDep(i)/ TotDepCapacity(i);
    ArrUtilizationRatio(i) = NbArr(i)/TotArrCapacity(i);
    DepRunwayUtilizationRatio(i) = NbDep(i) / (DepCapacityperHour(i) * 18);
    ArrRunwayUtilizationRatio(i) = NbArr(i) / (ArrCapacityperHour(i) * 18);
    TotalAircraft(i) = NbDep(i)+ NbArr(i);
    TotalCapacity(i) = TotDepCapacity(i)+TotArrCapacity(i);
    TotalUtilizationRatio(i) = TotalAircraft(i)/TotalCapacity(i);

end

AllAvTotDelays(run,:) = AvTotalDelay;
AllArrUtilizationRatio(run,:) = ArrUtilizationRatio;
AllDepUtilizationRatio(run,:) = DepUtilizationRatio;
AllDepRunwayUtilizationRatio(run,:) = DepRunwayUtilizationRatio;
AllArrRunwayUtilizationRatio(run,:) = ArrRunwayUtilizationRatio;
AllTotalAircraft(run,:) = TotalAircraft;
AllTotalCapacity(run,:) = TotalCapacity;
AllTotalUtilizationRatio(run,:) = TotalUtilizationRatio;
AllNbDep(run,:) = NbDep;
AllNbArr(run,:) = NbArr;
AllPerSmallAC(run,:) = PerSmallAC;
AllNbAC(run,:) = NbAC;
AllTotArrCapacity(run,:) = TotArrCapacity;
AllTotDepCapacity(run,:) = TotDepCapacity;
AllAvArrDelays(run,:) = AvArrDelays;
```

```
AllAvDepDelays(run,:) = AvDepDelays;
AllAvRunwayCongDelay(run,:) = AvRunwayCongDelay;
AllDepCapacityperHour(run,:) = DepCapacityperHour;
AllArrCapacityperHour(run,:) = ArrCapacityperHour;

%Save data in Excel spreadsheet

SaveAllRunsS2withTech(k,AllAvTotDelays,AllArrUtilizationRatio,AllDepUtilizationRatio,
    AllTotalAircraft,AllTotalCapacity,AllTotalUtilizationRatio,
    AllDepRunwayUtilizationRatio,AllArrRunwayUtilizationRatio,AllNbDep,AllNbArr,
    AllPerSmallAC,AllNbAC,AllTotArrCapacity,AllTotDepCapacity,AllAvArrDelays,
    AllAvDepDelays,AllAvRunwayCongDelay,AllDepCapacityperHour,AllArrCapacityperHour);

AverageofAverageTotalDelayS2 = AverageofAverageTotalDelayS2 + AllAvTotDelays(run,:);
AverageofArrUtilizationRatioS2 = AverageofArrUtilizationRatioS2 +
    AllArrUtilizationRatio(run,:);
AverageofDepUtilizationRatioS2 = AverageofDepUtilizationRatioS2 +
    AllDepUtilizationRatio(run,:);
AverageofTotalAircraftS2 = AverageofTotalAircraftS2 +  AllTotalAircraft(run,:);
AverageofTotalCapacityS2 = AverageofTotalCapacityS2 +  AllTotalCapacity(run,:);
AverageofTotalUtilizationRatioS2 = AverageofTotalUtilizationRatioS2 +
    AllTotalUtilizationRatio(run,:);
AverageofDepRunwayUtilizationRatioS2 = AverageofDepRunwayUtilizationRatioS2 +
    AllDepRunwayUtilizationRatio(run,:);
AverageofArrRunwayUtilizationRatioS2 = AverageofArrRunwayUtilizationRatioS2 +
    AllArrRunwayUtilizationRatio(run,:);
AverageofNbDepS2 = AverageofNbDepS2 + AllNbDep(run,:);
AverageofNbArrS2 = AverageofNbArrS2  + AllNbArr(run,:);
AverageofPerSmallACS2 = AverageofPerSmallACS2 + AllPerSmallAC(run,:);
AverageofNbACS2 = AverageofNbACS2 + AllNbAC(run,:);
AverageofTotArrCapacityS2 =  AverageofTotArrCapacityS2 + AllTotArrCapacity(run,:);
AverageofTotDepCapacityS2 =  AverageofTotDepCapacityS2 + AllTotDepCapacity(run,:);
AverageofArrDelaysS2 =  AverageofArrDelaysS2 + AllAvArrDelays(run,:);
AverageofDepDelaysS2 =  AverageofDepDelaysS2 + AllAvDepDelays(run,:);
AverageofAvRunwayCongDelayS2 = AverageofAvRunwayCongDelayS2 + AllAvRunwayCongDelay(run
    ,:);
AverageofDepCapacityperHourS2 = AverageofDepCapacityperHourS2 + AllDepCapacityperHour(
    run,:);
AverageofArrCapacityperHourS2 = AverageofArrCapacityperHourS2 + AllArrCapacityperHour(
    run,:);
```

```
    run = run+1;

end


AverageofAverageTotalDelayS2 = AverageofAverageTotalDelayS2/TotalNbRuns;
AverageofArrUtilizationRatioS2 = AverageofArrUtilizationRatioS2/TotalNbRuns;
AverageofDepUtilizationRatioS2 = AverageofDepUtilizationRatioS2/TotalNbRuns;
AverageofTotalAircraftS2  = AverageofTotalAircraftS2/TotalNbRuns;
AverageofTotalCapacityS2 = AverageofTotalCapacityS2/TotalNbRuns;
AverageofTotalUtilizationRatioS2 = AverageofTotalUtilizationRatioS2/TotalNbRuns;
AverageofDepRunwayUtilizationRatioS2 = AverageofDepRunwayUtilizationRatioS2/TotalNbRuns;
AverageofArrRunwayUtilizationRatioS2 = AverageofArrRunwayUtilizationRatioS2/TotalNbRuns;
AverageofNbDepS2 = AverageofNbDepS2/TotalNbRuns;
AverageofNbArrS2 = AverageofNbArrS2/TotalNbRuns;
AverageofPerSmallACS2 = AverageofPerSmallACS2/TotalNbRuns;
AverageofNbACS2 = AverageofNbACS2/TotalNbRuns;
AverageofTotArrCapacityS2 = AverageofTotArrCapacityS2/TotalNbRuns;
AverageofTotDepCapacityS2 = AverageofTotDepCapacityS2/TotalNbRuns;
AverageofArrDelaysS2 = AverageofArrDelaysS2/TotalNbRuns;
AverageofDepDelaysS2 = AverageofDepDelaysS2/TotalNbRuns;
AverageofAvRunwayCongDelayS2 = AverageofAvRunwayCongDelayS2/TotalNbRuns;
AverageofDepCapacityperHourS2 = AverageofDepCapacityperHourS2/TotalNbRuns;
AverageofArrCapacityperHourS2 = AverageofArrCapacityperHourS2/TotalNbRuns;

%Save data in Excel spreadsheet


xlswrite('5yearswithnoTechS2.xls', [AverageofAverageTotalDelay],'AverageTotalDelay');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrUtilizationRatio],'ArrUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepUtilizationRatio],'DepUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotalAircraft],'TotalAircraft');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotalCapacity],'TotalCapacity');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotalUtilizationRatio],'TotalUtilizationRatio
    ');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepRunwayUtilizationRatio],'
    DepRunwayUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrRunwayUtilizationRatio],'
    ArrRunwayUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofNbDep],'NbDep');
xlswrite('5yearswithnoTechS2.xls', [AverageofNbArr],'NbArr');
xlswrite('5yearswithnoTechS2.xls', [AverageofPerSmallAC],'PerSmallAC');
xlswrite('5yearswithnoTechS2.xls', [AverageofNbAC],'NbAC');
```

```
xlswrite('5yearswithnoTechS2.xls', [AverageofTotArrCapacity],'TotArrCapacity');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotDepCapacity],'TotDepCapacity');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrDelays],'ArrDelays');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepDelays],'DepDelays');
xlswrite('5yearswithnoTechS2.xls', [AverageofAvRunwayCongDelay],'AvRunwayCongDelay');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepCapacityperHour],'DepCapacityperHour');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrCapacityperHour],'CapacityperHour');


end
```

F.20 RunT10.m

```
function[AverageofAverageTotalDelayS2, AverageofArrUtilizationRatioS2,
    AverageofDepUtilizationRatioS2, AverageofTotalAircraftS2, AverageofTotalCapacityS2,
    AverageofTotalUtilizationRatioS2, AverageofDepRunwayUtilizationRatioS2,
    AverageofArrRunwayUtilizationRatioS2, AverageofNbDepS2, AverageofNbArrS2,
    AverageofPerSmallACS2, AverageofNbACS2, AverageofTotArrCapacityS2,
    AverageofTotDepCapacityS2, AverageofArrDelaysS2, AverageofDepDelaysS2,
    AverageofAvRunwayCongDelayS2, AverageofDepCapacityperHourS2,
    AverageofArrCapacityperHourS2]=RunT10(MaxAC,MaxPerc,k,NewImpact,NbPortfolios)

TimebtwDecisions =15; %years
lengthrun = 15; %years
TotalNbofArrACInitial = MaxAC;
PerSMALLacArrInitial  = MaxPerc;
time = zeros(1,TimebtwDecisions);
TotalNbofArrAC = zeros(1,TimebtwDecisions);
AvTotalDelay = zeros(1,TimebtwDecisions);
NbAC = zeros(1,TimebtwDecisions);
PerSmallAC = zeros(1,TimebtwDecisions);
TotArrCapacity = zeros(1,TimebtwDecisions);
TotDepCapacity =  zeros(1,TimebtwDecisions);
AvArrDelays =  zeros(1,TimebtwDecisions);
AvDepDelays = zeros(1,TimebtwDecisions);
NbDep = zeros(1,TimebtwDecisions);
NbArr = zeros(1,TimebtwDecisions);
DepUtilizationRatio = zeros(1,TimebtwDecisions);
ArrUtilizationRatio = zeros(1,TimebtwDecisions);
UtilizationRatio = zeros(1,TimebtwDecisions);
TotalAircraft = zeros(1,TimebtwDecisions);
TotalCapacity = zeros(1,TimebtwDecisions);
TotalUtilizationRatio = zeros(1,TimebtwDecisions);
AvRunwayCongDelay = zeros(1,TimebtwDecisions);
ArrCapacityperHour = zeros(1,TimebtwDecisions);
DepCapacityperHour = zeros(1,TimebtwDecisions);
DepRunwayUtilizationRatio = zeros(1,TimebtwDecisions);
ArrRunwayUtilizationRatio = zeros(1,TimebtwDecisions);
```

```
CongThreshold = 0.055;

%INTERACT WITH MACAD MODEL

[HBGrowthRate HBFleetMix LBGrowthRate LBFleetMix] = Traffic();

%To initialize COM client

mc = actxserver('ModelCenter.Application');

%To load MACAD model

invoke(mc,'loadModel','C:\Users\opinon\Documents\WorksInProgressWithoutSurrogate\
    MACAD2SoloDec2011.pxc');

%Assign Tech values to the model

invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ApproachSpeedSMALLAC', NewImpact(k,1));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ApproachSpeedMEDIUMAC', NewImpact(k,2));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrRunwayOccTimeforSMALLacinsec',
    NewImpact(k,3));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrRunwayOccTimeforMEDIUMacinsec',
    NewImpact(k,4));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepRunwayOccTimeforSMALLacinsec',
    NewImpact(k,5));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepRunwayOccTimeforMEDIUMacinsec',
    NewImpact(k,6));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.ArrivalsTaxiAverage', NewImpact(k,7));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.DepTaxiAverage', NewImpact(k,8));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACSMALLFollowSMALL',
    NewImpact(k,9));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACSMALLFollowMEDIUM',
    NewImpact(k,10));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACMEDIUMFollowSMALL' ,
    NewImpact(k,11));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinSepApproachingACMEDIUMFollowMEDIUM',
    NewImpact(k,12));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepSMALLFollowSMALL', NewImpact
    (k,13));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepSMALLFollowMEDIUM',
    NewImpact(k,14));
```

```
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepMEDIUMFollowSMALL',
    NewImpact(k,15));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinInterDepSepMEDIUMFollowMEDIUM',
    NewImpact(k,16));
invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.MinArrDepSeparation', NewImpact(k,17));

TotalNbRuns = 500;

AllAvTotDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllArrUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllDepUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalAircraft = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllTotalUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllDepRunwayUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllArrRunwayUtilizationRatio = zeros(TotalNbRuns,TimebtwDecisions);
AllNbDep = zeros(TotalNbRuns,TimebtwDecisions);
AllNbArr = zeros(TotalNbRuns,TimebtwDecisions);
AllPerSmallAC = zeros(TotalNbRuns,TimebtwDecisions);
AllNbAC = zeros(TotalNbRuns,TimebtwDecisions);
AllTotArrCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllTotDepCapacity = zeros(TotalNbRuns,TimebtwDecisions);
AllAvArrDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllAvDepDelays = zeros(TotalNbRuns,TimebtwDecisions);
AllAvRunwayCongDelay = zeros(TotalNbRuns,TimebtwDecisions);
AllDepCapacityperHour = zeros(TotalNbRuns,TimebtwDecisions);
AllArrCapacityperHour = zeros(TotalNbRuns,TimebtwDecisions);

AverageofAverageTotalDelayS2 = zeros(1,TimebtwDecisions);
AverageofArrUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofDepUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofTotalAircraftS2 = zeros(1,TimebtwDecisions);
AverageofTotalCapacityS2 = zeros(1,TimebtwDecisions);
AverageofTotalUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofDepRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofArrRunwayUtilizationRatioS2 = zeros(1,TimebtwDecisions);
AverageofNbDepS2 = zeros(1,TimebtwDecisions);
AverageofNbArrS2 = zeros(1,TimebtwDecisions);
AverageofPerSmallACS2 = zeros(1,TimebtwDecisions);
AverageofNbACS2 = zeros(1,TimebtwDecisions);
AverageofTotArrCapacityS2 =  zeros(1,TimebtwDecisions);
```

```
AverageofTotDepCapacityS2 =  zeros(1,TimebtwDecisions);
AverageofArrDelaysS2 =  zeros(1,TimebtwDecisions);
AverageofDepDelaysS2 =  zeros(1,TimebtwDecisions);
AverageofAvRunwayCongDelayS2 = zeros(1,TimebtwDecisions);
AverageofDepCapacityperHourS2 = zeros(1,TimebtwDecisions);
AverageofArrCapacityperHourS2 = zeros(1,TimebtwDecisions);

for run = 1:TotalNbRuns

    TotalNbofArrACInitial = MaxAC;
    PerSMALLacArrInitial  = MaxPerc;

    for i=1:1:5

        GRrandom = str2double(LBGrowthRate{1}) + rand(1,1) * (str2double(HBGrowthRate{1}) - str2double(LBGrowthRate{1}));  %Uniform distribution between the bound set in database
        FMrandom = str2double(LBFleetMix{1}) + rand(1,1) * (str2double(HBFleetMix{1}) - str2double(LBFleetMix{1})); %Uniform distribution between the bound set in database

        TotalNbofArrAC(i) =  TotalNbofArrACInitial + TotalNbofArrACInitial * GRrandom/100;
        PerSMALLacArr(i) =  PerSMALLacArrInitial +  PerSMALLacArrInitial * FMrandom/100;

        %Assign values to traffic inputs

        invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.TotalNbofArrAC',TotalNbofArrAC(i));
        invoke(mc,'setValue','MACAD2Model.MACAD2Wrapper.PerSMALLacArr',PerSMALLacArr(i));

        TotalNbofArrACInitial = TotalNbofArrAC(i);
        PerSMALLacArrInitial = PerSMALLacArr(i);

        %Run MACAD and retrieve outputs of interest

        NbAC(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.TotalNbofArrAC');
        PerSmallAC(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.PerSMALLacArr');
        AvTotalDelay(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvTotalDelays');
        TotArrCapacity(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.TotArrCapacity');
```

```
    TotDepCapacity(i) =  invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        TotDepCapacity');
    AvArrDelays(i) =  invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvArrDelays');
    AvDepDelays(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.AvDepDelay');
    AvRunwayCongDelay(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        AvRunwayCongDelay');
    NbDep(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.NbDep');
    NbArr(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.NbArrivals');
    ArrCapacityperHour(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        ArrivalCapacityperHourEvenMix');
    DepCapacityperHour(i) = invoke(mc,'getValue','MACAD2Model.MACAD2Wrapper.
        DepartureCapacityperHourEvenMix');

    % Calculate utilizatio ratios
    DepUtilizationRatio(i) = NbDep(i)/ TotDepCapacity(i);
    ArrUtilizationRatio(i) = NbArr(i)/TotArrCapacity(i);
    DepRunwayUtilizationRatio(i) = NbDep(i) / (DepCapacityperHour(i) * 18);
    ArrRunwayUtilizationRatio(i) = NbArr(i) / (ArrCapacityperHour(i) * 18);
    TotalAircraft(i) = NbDep(i)+ NbArr(i);
    TotalCapacity(i) = TotDepCapacity(i)+TotArrCapacity(i);
    TotalUtilizationRatio(i) = TotalAircraft(i)/TotalCapacity(i);

end

AllAvTotDelays(run,:) = AvTotalDelay;
AllArrUtilizationRatio(run,:) = ArrUtilizationRatio;
AllDepUtilizationRatio(run,:) = DepUtilizationRatio;
AllDepRunwayUtilizationRatio(run,:) = DepRunwayUtilizationRatio;
AllArrRunwayUtilizationRatio(run,:) = ArrRunwayUtilizationRatio;
AllTotalAircraft(run,:) = TotalAircraft;
AllTotalCapacity(run,:) = TotalCapacity;
AllTotalUtilizationRatio(run,:) = TotalUtilizationRatio;
AllNbDep(run,:) = NbDep;
AllNbArr(run,:) = NbArr;
AllPerSmallAC(run,:) = PerSmallAC;
AllNbAC(run,:) = NbAC;
AllTotArrCapacity(run,:) = TotArrCapacity;
AllTotDepCapacity(run,:) = TotDepCapacity;
AllAvArrDelays(run,:) = AvArrDelays;
AllAvDepDelays(run,:) = AvDepDelays;
AllAvRunwayCongDelay(run,:) = AvRunwayCongDelay;
```

```
AllDepCapacityperHour(run,:) = DepCapacityperHour;
AllArrCapacityperHour(run,:) = ArrCapacityperHour;

%Save data in Excel spreadsheet

SaveAllRunsS3withTech(k,AllAvTotDelays,AllArrUtilizationRatio,AllDepUtilizationRatio,
    AllTotalAircraft,AllTotalCapacity,AllTotalUtilizationRatio,
    AllDepRunwayUtilizationRatio,AllArrRunwayUtilizationRatio,AllNbDep,AllNbArr,
    AllPerSmallAC,AllNbAC,AllTotArrCapacity,AllTotDepCapacity,AllAvArrDelays,
    AllAvDepDelays,AllAvRunwayCongDelay,AllDepCapacityperHour,AllArrCapacityperHour);

xlswrite('5yearswithTechS3NoAv.xls', [AllAvTotDelays],'AverageTotalDelay');
xlswrite('5yearswithTechS3NoAv.xls', [AllArrUtilizationRatio],'ArrUtilizationRatio');
xlswrite('5yearswithTechS3NoAv.xls', [AllDepUtilizationRatio],'DepUtilizationRatio');
xlswrite('5yearswithTechS3NoAv.xls', [AllTotalAircraft],'TotalAircraft');
xlswrite('5yearswithTechS3NoAv.xls', [AllTotalCapacity],'TotalCapacity');
xlswrite('5yearswithTechS3NoAv.xls', [AllTotalUtilizationRatio],'TotalUtilizationRatio
    ');
xlswrite('5yearswithTechS3NoAv.xls', [AllDepRunwayUtilizationRatio],'
    DepRunwayUtilizationRatio');
xlswrite('5yearswithTechS3NoAv.xls', [AllArrRunwayUtilizationRatio],'
    ArrRunwayUtilizationRatio');
xlswrite('5yearswithTechS3NoAv.xls', [AllNbDep],'NbDep');
xlswrite('5yearswithTechS3NoAv.xls', [AllNbArr],'NbArr');
xlswrite('5yearswithTechS3NoAv.xls', [AllPerSmallAC],'PerSmallAC');
xlswrite('5yearswithTechS3NoAv.xls', [AllNbAC],'NbAC');
xlswrite('5yearswithTechS3NoAv.xls', [AllTotArrCapacity],'TotArrCapacity');
xlswrite('5yearswithTechS3NoAv.xls', [AllTotDepCapacity],'TotDepCapacity');
xlswrite('5yearswithTechS3NoAv.xls', [AllAvArrDelays],'ArrDelays');
xlswrite('5yearswithTechS3NoAv.xls', [AllAvDepDelays],'DepDelays');
xlswrite('5yearswithTechS3NoAv.xls', [AllAvRunwayCongDelay],'AvRunwayCongDelay');
xlswrite('5yearswithTechS3NoAv.xls', [AllDepCapacityperHour],'DepCapacityperHour');
xlswrite('5yearswithTechS3NoAv.xls', [AllArrCapacityperHour],'CapacityperHour');

AverageofAverageTotalDelayS2 = AverageofAverageTotalDelayS2 + AllAvTotDelays(run,:);
AverageofArrUtilizationRatioS2 = AverageofArrUtilizationRatioS2 +
    AllArrUtilizationRatio(run,:);
AverageofDepUtilizationRatioS2 = AverageofDepUtilizationRatioS2 +
    AllDepUtilizationRatio(run,:);
AverageofTotalAircraftS2 = AverageofTotalAircraftS2 +  AllTotalAircraft(run,:);
AverageofTotalCapacityS2 = AverageofTotalCapacityS2 +  AllTotalCapacity(run,:);
```

```
    AverageofTotalUtilizationRatioS2 = AverageofTotalUtilizationRatioS2 +
        AllTotalUtilizationRatio(run,:);
    AverageofDepRunwayUtilizationRatioS2 = AverageofDepRunwayUtilizationRatioS2 +
        AllDepRunwayUtilizationRatio(run,:);
    AverageofArrRunwayUtilizationRatioS2 = AverageofArrRunwayUtilizationRatioS2 +
        AllArrRunwayUtilizationRatio(run,:);
    AverageofNbDepS2 = AverageofNbDepS2 + AllNbDep(run,:);
    AverageofNbArrS2 = AverageofNbArrS2  + AllNbArr(run,:);
    AverageofPerSmallACS2 = AverageofPerSmallACS2 + AllPerSmallAC(run,:);
    AverageofNbACS2 = AverageofNbACS2 + AllNbAC(run,:);
    AverageofTotArrCapacityS2 =  AverageofTotArrCapacityS2 + AllTotArrCapacity(run,:);
    AverageofTotDepCapacityS2 =  AverageofTotDepCapacityS2 + AllTotDepCapacity(run,:);
    AverageofArrDelaysS2 =  AverageofArrDelaysS2 + AllAvArrDelays(run,:);
    AverageofDepDelaysS2 =  AverageofDepDelaysS2 + AllAvDepDelays(run,:);
    AverageofAvRunwayCongDelayS2 = AverageofAvRunwayCongDelayS2 + AllAvRunwayCongDelay(run
        ,:);
    AverageofDepCapacityperHourS2 = AverageofDepCapacityperHourS2 + AllDepCapacityperHour(
        run,:);
    AverageofArrCapacityperHourS2 = AverageofArrCapacityperHourS2 + AllArrCapacityperHour(
        run,:);

    run = run+1;

end

AverageofAverageTotalDelayS2 = AverageofAverageTotalDelayS2/TotalNbRuns;
AverageofArrUtilizationRatioS2 = AverageofArrUtilizationRatioS2/TotalNbRuns;
AverageofDepUtilizationRatioS2 = AverageofDepUtilizationRatioS2/TotalNbRuns;
AverageofTotalAircraftS2  = AverageofTotalAircraftS2/TotalNbRuns;
AverageofTotalCapacityS2 = AverageofTotalCapacityS2/TotalNbRuns;
AverageofTotalUtilizationRatioS2 = AverageofTotalUtilizationRatioS2/TotalNbRuns;
AverageofDepRunwayUtilizationRatioS2 = AverageofDepRunwayUtilizationRatioS2/TotalNbRuns;
AverageofArrRunwayUtilizationRatioS2 = AverageofArrRunwayUtilizationRatioS2/TotalNbRuns;
AverageofNbDepS2 = AverageofNbDepS2/TotalNbRuns;
AverageofNbArrS2 = AverageofNbArrS2/TotalNbRuns;
AverageofPerSmallACS2 = AverageofPerSmallACS2/TotalNbRuns;
AverageofNbACS2 = AverageofNbACS2/TotalNbRuns;
AverageofTotArrCapacityS2 = AverageofTotArrCapacityS2/TotalNbRuns;
AverageofTotDepCapacityS2 = AverageofTotDepCapacityS2/TotalNbRuns;
AverageofArrDelaysS2 = AverageofArrDelaysS2/TotalNbRuns;
AverageofDepDelaysS2 = AverageofDepDelaysS2/TotalNbRuns;
```

```
AverageofAvRunwayCongDelayS2 = AverageofAvRunwayCongDelayS2/TotalNbRuns;
AverageofDepCapacityperHourS2 = AverageofDepCapacityperHourS2/TotalNbRuns;
AverageofArrCapacityperHourS2 = AverageofArrCapacityperHourS2/TotalNbRuns;

%Save data in Excel spreadsheet

xlswrite('5yearswithnoTechS2.xls', [AverageofAverageTotalDelay],'AverageTotalDelay');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrUtilizationRatio],'ArrUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepUtilizationRatio],'DepUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotalAircraft],'TotalAircraft');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotalCapacity],'TotalCapacity');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotalUtilizationRatio],'TotalUtilizationRatio
    ');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepRunwayUtilizationRatio],'
    DepRunwayUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrRunwayUtilizationRatio],'
    ArrRunwayUtilizationRatio');
xlswrite('5yearswithnoTechS2.xls', [AverageofNbDep],'NbDep');
xlswrite('5yearswithnoTechS2.xls', [AverageofNbArr],'NbArr');
xlswrite('5yearswithnoTechS2.xls', [AverageofPerSmallAC],'PerSmallAC');
xlswrite('5yearswithnoTechS2.xls', [AverageofNbAC],'NbAC');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotArrCapacity],'TotArrCapacity');
xlswrite('5yearswithnoTechS2.xls', [AverageofTotDepCapacity],'TotDepCapacity');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrDelays],'ArrDelays');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepDelays],'DepDelays');
xlswrite('5yearswithnoTechS2.xls', [AverageofAvRunwayCongDelay],'AvRunwayCongDelay');
xlswrite('5yearswithnoTechS2.xls', [AverageofDepCapacityperHour],'DepCapacityperHour');
xlswrite('5yearswithnoTechS2.xls', [AverageofArrCapacityperHour],'CapacityperHour');

end
```

F.21 SetupGame.m

```
function SetupGame(TimeInterval)


gameinterval = ['GAME>GAMEINTERVAL|',num2str(TimeInterval)];
lp5=libpointer('voidPtr',[int8(gameinterval) 0]);
r11 = calllib('VenDLL32','vensim_command',gameinterval);


end
```

F.22 TechCombinedImpact.m

```
function TotalImpact = TechCombinedImpact(metricValue, AllTechID)

%clear all

%Connection to server and database
[dbConn] = ConnectToDB();

%Initialization
TotalImpact = 0;
alpha = 1.2;

%Identify all technologies that support the given metric
SQLqueryTech2 = ['select Tech from TIM where Metric = ', num2str(metricValue)]; %Retrieve
    technologies that have an impact on the same metric
TechMetric = fetch(dbConn, SQLqueryTech2);

if (isempty(TechMetric)) %If there is no such metric
    return
end

%Only look at Techs that are common to both AllTechID and TechMetric
k = 1;
TechM = cell(0);
for i=1:1:length(AllTechID)
    for j=1:1:length(TechMetric)
        if num2str(AllTechID{i}) == num2str(TechMetric{j})
            TechM{k} = num2str(AllTechID{i});
            k = k+1;
        end
    end
end

if length(TechM)==0 %if there are no common technologies for that metric
    return
end

n=zeros(1,length(TechM));
```

```
if length(TechM) < 2
    SQLqueryLBImpacti = ['select LBImpact from TIM where Tech = ',num2str(TechM{1})];
    LBImpacti = fetch(dbConn, SQLqueryLBImpacti);
    SQLqueryHBImpacti = ['select HBImpact from TIM where Tech = ',num2str(TechM{1})];
    HBImpacti = fetch(dbConn, SQLqueryHBImpacti);
    Impacti = str2double(LBImpacti{1}) + rand(1,1) * (str2double(HBImpacti{1}) -
        str2double(LBImpacti{1})); %Uniform distribution between the bounds set in
        database
    TotalImpact = TotalImpact + Impacti;

else
    for i=1:1:length(TechM);  %Check the nature of the relationship between these
        technologies
        for j=i+1:1:length(TechM);

            SQLquerymij = ['select mij from BinaryMatrix where Techi =',num2str(TechM{i}),
                ' and Techj =',num2str(TechM{j})];
            mij = fetch(dbConn,SQLquerymij);
            SQLquerymji = ['select mij from BinaryMatrix where Techi =',num2str(TechM{j}),
                ' and Techj =',num2str(TechM{i})];
            mji = fetch(dbConn,SQLquerymji);

            if cell2mat(mij) == 1

                SQLqueryLBImpacti = ['select LBImpact from TIM where Tech = ',num2str(
                    TechM{i})];
                LBImpacti = fetch(dbConn, SQLqueryLBImpacti);
                SQLqueryHBImpacti = ['select HBImpact from TIM where Tech = ',num2str(
                    TechM{i})];
                HBImpacti = fetch(dbConn, SQLqueryHBImpacti);
                Impacti = str2double(LBImpacti{1}) + rand(1,1) * (str2double(HBImpacti{1})
                     - str2double(LBImpacti{1})); %Uniform distribution between the bounds
                     set in database

                % ************* TEST FOR SYNERGISTIC INFLUENCE ************
                if cell2mat(mji) == 1  %Test for synergistic influence

                    SQLqueryLBImpactj = ['select LBImpact from TIM where Tech = ',num2str(
                        TechM{j})];
                    LBImpactj = fetch(dbConn, SQLqueryLBImpactj);
```

```
            SQLqueryHBImpactj = ['select HBImpact from TIM where Tech = ',num2str(
                TechM{j})];
            HBImpactj = fetch(dbConn, SQLqueryHBImpactj);
            Impactj = str2double(LBImpactj{1}) + rand(1,1) * (str2double(HBImpactj
                {1}) - str2double(LBImpactj{1})); %Uniform distribution between
                the bounds set in database

            TotalImpact = TotalImpact + alpha*(Impacti+Impactj);  %alpha set to
                1.2 for every synergistic relationships

            n(i) = n(i) + 1;
            n(j) = n(j) + 1;

            % ******* TEST FOR UNILATERAL INFLUENCE (j->i) *******
        else
            Unilaterali = 0;
            for p=1:1:length(TechM);

                if ( p≠ i && p≠j)
                    SQLquerympi = ['select mij from BinaryMatrix where Techi =',
                        num2str(TechM{p}),' and Techj =',num2str(TechM{i})];
                    mpi = fetch(dbConn,SQLquerympi);
                    if (isempty(mpi))
                        Unilaterali = 0;
                    else
                        Unilaterali = Unilaterali + str2double(mpi);
                    end
                end
            end
            n(j) = n(j) + 1;

            if Unilaterali == 0
                SQLqueryLBImpacti = ['select LBImpact from TIM where Tech = ',
                    num2str(TechM{i})];
                LBImpacti = fetch(dbConn, SQLqueryLBImpacti);
                SQLqueryHBImpacti = ['select HBImpact from TIM where Tech = ',
                    num2str(TechM{i})];
                HBImpacti = fetch(dbConn, SQLqueryHBImpacti);
                Impacti = str2double(LBImpacti{1}) + rand(1,1) * (str2double(
                    HBImpacti{1}) - str2double(LBImpacti{1})); %Uniform
                    distribution between the bounds set in database
```

```
            TotalImpact = TotalImpact + Impacti;
            n(i) = n(i) + 1;

            if n(i) > 1
                TotalImpact = TotalImpact - Impacti;
                n(i) = 1;
            end
        end
        TotalImpact;
    end
else

    % ********* TEST FOR UNILATERAL INFLUENCE (i->j) **********
    if cell2mat(mji) == 1
        Unilateralj = 0;
        for p=1:1:length(TechM);
            if (p ≠i && p≠j)
                SQLquerympj = ['select mij from BinaryMatrix where Techi =',
                    num2str(TechM{p}),' and Techj =',num2str(TechM{j})];
                mpj = fetch(dbConn,SQLquerympj);

                if (isempty(mpj))
                    Unilateralj = 0;
                else
                    Unilateralj = Unilateralj + str2double(mpj);
                end

            end
            n(i) = n(i) + 1;

            if Unilateralj == 0
                SQLqueryLBImpactj = ['select LBImpact from TIM where Tech = ',
                    num2str(TechM{j})];
                LBImpactj = fetch(dbConn, SQLqueryLBImpactj);
                SQLqueryHBImpactj = ['select HBImpact from TIM where Tech = ',
                    num2str(TechM{j})];
                HBImpactj = fetch(dbConn, SQLqueryHBImpactj);
                Impactj = str2double(LBImpactj{1}) + rand(1,1) * (str2double(
                    HBImpactj{1}) - str2double(LBImpactj{1})); %Uniform
                    distribution between the bounds set in database
```

```
                TotalImpact = TotalImpact + Impactj;
                n(j) = n(j) + 1;

                if n(j) > 1
                    TotalImpact = TotalImpact - Impactj;
                    n(j) = 1;
                end
            end
        end
        TotalImpact;
    else

        % *************** TEST FOR NO INFLUENCE **************
        NoInfluencei = 0;
        NoInfluencej = 0;

        for p=1:1:length(TechM);

            if p ≠ i
                SQLquerympi = ['select mij from BinaryMatrix where Techi =',
                    num2str(TechM{p}),' and Techj =',num2str(TechM{i})];
                mpi = fetch(dbConn,SQLquerympi);
                SQLquerymip = ['select mij from BinaryMatrix where Techi =',
                    num2str(TechM{i}),' and Techj =',num2str(TechM{p})];
                mip = fetch(dbConn,SQLquerymip);

                if (isempty(mip) && isempty(mpi))
                    NoInfluencei = 0;
                else
                    NoInfluencei = str2double(mpi) + str2double(mip);
                end;
            end

            if p ≠ j
                SQLquerympj = ['select mij from BinaryMatrix where Techi =',
                    num2str(TechM{p}),' and Techj =',num2str(TechM{j})];
                mpj = fetch(dbConn,SQLquerympj);
                SQLquerymjp = ['select mij from BinaryMatrix where Techi =',
                    num2str(TechM{j}),' and Techj =',num2str(TechM{p})];
                mjp = fetch(dbConn,SQLquerymjp);
```

```
            if (isempty(mjp) && isempty(mpj))
                NoInfluencej = 0;
            else
                NoInfluencej = str2double(mpj) + str2double(mjp);
            end;
        end
    end

    if NoInfluencei == 0
        SQLqueryLBImpacti = ['select LBImpact from TIM where Tech = ',
            num2str(TechM{i})];
        LBImpacti = fetch(dbConn, SQLqueryLBImpacti);
        SQLqueryHBImpacti = ['select HBImpact from TIM where Tech = ',
            num2str(TechM{i})];
        HBImpacti = fetch(dbConn, SQLqueryHBImpacti);
        Impacti = str2double(LBImpacti{1}) + rand(1,1) * (str2double(
            HBImpacti{1}) - str2double(LBImpacti{1})); %Uniform
            distribution between the bounds set in database

        TotalImpact = TotalImpact + Impacti;
        n(i) = n(i) + 1;
        if n(i) > 1
            TotalImpact = TotalImpact - Impacti;
            n(i) = 1;
        end
    end

    if NoInfluencej == 0
        SQLqueryLBImpactj = ['select LBImpact from TIM where Tech = ',
            num2str(TechM{j})];
        LBImpactj = fetch(dbConn, SQLqueryLBImpactj);
        SQLqueryHBImpactj = ['select HBImpact from TIM where Tech = ',
            num2str(TechM{j})];
        HBImpactj = fetch(dbConn, SQLqueryHBImpactj);
        Impactj = str2double(LBImpactj{1}) + rand(1,1) * (str2double(
            HBImpactj{1}) - str2double(LBImpactj{1})); %Uniform
            distribution between the bounds set in database

        TotalImpact = TotalImpact + Impactj;
        n(j) = n(j) + 1;
```

```
                        if n(j) > 1
                            TotalImpact = TotalImpact - Impactj;
                            n(j) = 1;
                        end
                    end
                    TotalImpact;
                end
            end
        end
    end
end
```

F.23 Traffic.m

```
function [HBGrowthRate HBFleetMix LBGrowthRate LBFleetMix] = Traffic()

%Connection to server and database
[dbConn] = ConnectToDB();

scenarioGR = 'HIGH';
SQLqueryLBGR = ['select LowBound from ACOpForecast WHERE Scenario =''',scenarioGR,''''];
LBGrowthRate = fetch(dbConn, SQLqueryLBGR);
SQLqueryHBGR = ['select HighBound from ACOpForecast WHERE Scenario =''',scenarioGR,''''];
HBGrowthRate = fetch(dbConn, SQLqueryHBGR);

scenarioFM = 'HIGH';
SQLqueryLBFM = ['select LowBound from FleetMixForecast WHERE Scenario =''',scenarioFM,''''
    ];
LBFleetMix = fetch(dbConn, SQLqueryLBFM);
SQLqueryHBFM = ['select HighBound from FleetMixForecast WHERE Scenario =''',scenarioFM,'''
    '];
HBFleetMix = fetch(dbConn, SQLqueryHBFM);

end
```

APPENDIX G

IMPLEMENTATION

G.1 Descriptions of the Scenario #4 Portfolios for Airport #2

Table G.1: Scenario #4 portfolios and their technologies

Portfolios	Year 5 to Year 10	Year 10 to Year 15	Observations
$P_{2S4}1$	T_{30}	T_{30}, T_{28}	No flights after dark
$P_{2S4}2$	T_{30}	T_{30}, T_{21}	
$P_{2S4}3$	T_{30}	T_{30}, T_{5}	No flights after dark
$P_{2S4}4$	T_{30}	T_{30}, T_{3}	No flights after dark
$P_{2S4}5$	T_{30}	T_{30}, T_{29}	No flights after dark
$P_{2S4}6$	T_{30}	T_{30}, T_{28}, T_{21}	
$P_{2S4}7$	T_{30}	T_{30}, T_{28}, T_{5}	No flights after dark
$P_{2S4}8$	T_{30}	T_{30}, T_{28}, T_{3}	No flights after dark
$P_{2S4}9$	T_{30}	T_{30}, T_{28}, T_{29}	No flights after dark
$P_{2S4}10$	T_{30}	T_{30}, T_{21}, T_{5}	
$P_{2S4}11$	T_{30}	T_{30}, T_{21}, T_{3}	
$P_{2S4}12$	T_{30}	T_{30}, T_{21}, T_{29}	
$P_{2S4}13$	T_{30}	T_{30}, T_{5}, T_{3}	No flights after dark
$P_{2S4}14$	T_{30}	T_{30}, T_{5}, T_{29}	No flights after dark
$P_{2S4}15$	T_{30}	T_{30}, T_{3}, T_{29}	No flights after dark
$P_{2S4}16$	T_{30}	T_{30}, T_{28}, T_{21}, T_{5}	
$P_{2S4}17$	T_{30}	T_{30}, T_{28}, T_{21}, T_{3}	
$P_{2S4}18$	T_{30}	T_{30}, T_{28}, T_{21}, T_{29}	
$P_{2S4}19$	T_{30}	T_{30}, T_{28}, T_{5}, T_{3}	No flights after dark
$P_{2S4}20$	T_{30}	T_{30}, T_{28}, T_{5}, T_{29}	No flights after dark
$P_{2S4}21$	T_{30}	T_{30}, T_{28}, T_{3}, T_{29}	No flights after dark
$P_{2S4}22$	T_{30}	T_{30}, T_{21}, T_{5}, T_{3}	
$P_{2S4}23$	T_{30}	T_{30}, T_{21}, T_{5}, T_{29}	
$P_{2S4}24$	T_{30}	T_{30}, T_{21}, T_{3}, T_{29}	
$P_{2S4}25$	T_{30}	T_{30}, T_{5}, T_{3}, T_{29}	No flights after dark
$P_{2S4}26$	T_{30}	T_{30}, T_{28}, T_{21}, T_{5}, T_{3}	
$P_{2S4}27$	T_{30}	T_{30}, T_{28}, T_{21}, T_{5}, T_{29}	
$P_{2S4}28$	T_{30}	T_{30}, T_{28}, T_{21}, T_{3}, T_{29}	
$P_{2S4}29$	T_{30}	T_{30}, T_{28}, T_{5}, T_{3}, T_{29}	No flights after dark

Table G.2: Scenario #4 portfolios and their technologies (continued)

Portfolios	**Year 5 to Year 10**	**Year 10 to Year 15**	**Observations**
$P_{2S4}30$	T_{30}	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}31$	T_{30}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}32$	T_{21}	T_{30}, T_{21}	
$P_{2S4}33$	T_{21}	T_{28}, T_{21}	
$P_{2S4}34$	T_{21}	T_{21}, T_5	
$P_{2S4}35$	T_{21}	T_{21}, T_3	
$P_{2S4}36$	T_{21}	T_{21}, T_{29}	
$P_{2S4}37$	T_{21}	T_{30}, T_{28}, T_{21}	
$P_{2S4}38$	T_{21}	T_{30}, T_{21}, T_5	
$P_{2S4}39$	T_{21}	T_{30}, T_{21}, T_3	
$P_{2S4}40$	T_{21}	T_{30}, T_{21}, T_{29}	
$P_{2S4}41$	T_{21}	T_{28}, T_{21}, T_5	
$P_{2S4}42$	T_{21}	T_{28}, T_{21}, T_3	
$P_{2S4}43$	T_{21}	T_{28}, T_{21}, T_{29}	
$P_{2S4}44$	T_{21}	T_{21}, T_5, T_3	
$P_{2S4}45$	T_{21}	T_{21}, T_5, T_{29}	
$P_{2S4}46$	T_{21}	T_{21}, T_3, T_{29}	
$P_{2S4}47$	T_{21}	T_{30}, T_{28}, T_{21}, T_5	
$P_{2S4}48$	T_{21}	T_{30}, T_{28}, T_{21}, T_3	
$P_{2S4}49$	T_{21}	T_{30}, T_{28}, T_{21}, T_{29}	
$P_{2S4}50$	T_{21}	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}51$	T_{21}	T_{30}, T_{21}, T_5, T_{29}	
$P_{2S4}52$	T_{21}	T_{30}, T_{21}, T_3, T_{29}	
$P_{2S4}53$	T_{21}	T_{28}, T_{21}, T_5, T_3	
$P_{2S4}54$	T_{21}	T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}55$	T_{21}	T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}56$	T_{21}	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}57$	T_{21}	T_{30}, T_{28}, T_{21}, T_5, T_3	
$P_{2S4}58$	T_{21}	T_{30}, T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}59$	T_{21}	T_{30}, T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}60$	T_{21}	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}61$	T_{21}	T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}62$	T_{21}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}63$	T_5	T_{30}, T_5	No flights after dark
$P_{2S4}64$	T_5	T_{28}, T_5	No flights after dark
$P_{2S4}65$	T_5	T_5, T_3	No flights after dark
$P_{2S4}66$	T_5	T_{21}, T_5	
$P_{2S4}67$	T_5	T_5, T_{29}	No flights after dark
$P_{2S4}68$	T_5	T_{30}, T_{28}, T_5	No flights after dark
$P_{2S4}69$	T_5	T_{30}, T_{21}, T_5	
$P_{2S4}70$	T_5	T_{30}, T_5, T_3	No flights after dark

Table G.3: Scenario #4 portfolios and their technologies (continued)

Portfolios	Year 5 to Year 10	Year 10 to Year 15	Observations
$P_{2S4}71$	T_5	T_{30}, T_5, T_{29}	No flights after dark
$P_{2S4}72$	T_5	T_{28}, T_{21}, T_5	
$P_{2S4}73$	T_5	T_{28}, T_5, T_3	No flights after dark
$P_{2S4}74$	T_5	T_{28}, T_5, T_{29}	No flights after dark
$P_{2S4}75$	T_5	T_{21}, T_5, T_3	
$P_{2S4}76$	T_5	T_{21}, T_5, T_{29}	
$P_{2S4}77$	T_5	T_5, T_3, T_{29}	No flights after dark
$P_{2S4}78$	T_5	T_{30}, T_{28}, T_{21}, T_5	
$P_{2S4}79$	T_5	T_{30}, T_{28}, T_5, T_3	No flights after dark
$P_{2S4}80$	T_5	T_{30}, T_{28}, T_5, T_{29}	No flights after dark
$P_{2S4}81$	T_5	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}82$	T_5	T_{30}, T_{21}, T_5, T_{29}	
$P_{2S4}83$	T_5	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}84$	T_5	T_{28}, T_{21}, T_5, T_3	
$P_{2S4}85$	T_5	T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}86$	T_5	T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}87$	T_5	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}88$	T_5	T_{30}, T_{28}, T_{21}, T_5, T_3	
$P_{2S4}89$	T_5	T_{30}, T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}90$	T_5	T_{30}, T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}91$	T_5	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}92$	T_5	T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}93$	T_5	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}94$	T_3	T_{30}, T_3	No flights after dark
$P_{2S4}95$	T_3	T_{28}, T_3	No flights after dark
$P_{2S4}96$	T_3	T_{21}, T_3	
$P_{2S4}97$	T_3	T_5, T_3	No flights after dark
$P_{2S4}98$	T_3	T_3, T_{29}	No flights after dark
$P_{2S4}99$	T_3	T_{30}, T_{28}, T_3	No flights after dark
$P_{2S4}100$	T_3	T_{30}, T_{21}, T_3	
$P_{2S4}101$	T_3	T_{30}, T_5, T_3	No flights after dark
$P_{2S4}102$	T_3	T_{30}, T_3, T_{29}	No flights after dark
$P_{2S4}103$	T_3	T_{28}, T_{21}, T_3	
$P_{2S4}104$	T_3	T_{28}, T_5, T_3	No flights after dark
$P_{2S4}105$	T_3	T_{28}, T_3, T_{29}	No flights after dark
$P_{2S4}106$	T_3	T_{21}, T_5, T_3	
$P_{2S4}107$	T_3	T_{21}, T_3, T_{29}	
$P_{2S4}108$	T_3	T_5, T_3, T_{29}	No flights after dark
$P_{2S4}109$	T_3	T_{30}, T_{28}, T_{21}, T_3	
$P_{2S4}110$	T_3	T_{30}, T_{28}, T_5, T_3	No flights after dark
$P_{2S4}111$	T_3	T_{30}, T_{28}, T_3, T_{29}	No flights after dark

Table G.4: Scenario #4 portfolios and their technologies (continued)

Portfolios	Year 3 to Year 10	Year 10 to Year 13	Observations
$P_{2S4}112$	T_3	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}113$	T_3	$T_{30}, T_{21}, T_3, T_{29}$	
$P_{2S4}114$	T_3	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}115$	T_3	T_{28}, T_{21}, T_5, T_3	
$P_{2S4}116$	T_3	$T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}117$	T_3	T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}118$	T_3	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}119$	T_3	$T_{30}, T_{28}, T_{21}, T_5, T_3$	
$P_{2S4}120$	T_3	$T_{30}, T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}121$	T_3	$T_{30}, T_{28}, T_5, T_3, T_{29}$	No flights after dark
$P_{2S4}122$	T_3	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}123$	T_3	$T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}124$	T_3	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}125$	T_{29}	T_{30}, T_{29}	No flights after dark
$P_{2S4}126$	T_{29}	T_{28}, T_{29}	No flights after dark
$P_{2S4}127$	T_{29}	T_{21}, T_{29}	
$P_{2S4}128$	T_{29}	T_5, T_{29}	No flights after dark
$P_{2S4}129$	T_{29}	T_3, T_{29}	No flights after dark
$P_{2S4}130$	T_{29}	T_{30}, T_{28}, T_{29}	No flights after dark
$P_{2S4}131$	T_{29}	T_{30}, T_{21}, T_{29}	
$P_{2S4}132$	T_{29}	T_{30}, T_5, T_{29}	No flights after dark
$P_{2S4}133$	T_{29}	T_{30}, T_3, T_{29}	No flights after dark
$P_{2S4}134$	T_{29}	T_{28}, T_{21}, T_{29}	
$P_{2S4}135$	T_{29}	T_{28}, T_5, T_{29}	No flights after dark
$P_{2S4}136$	T_{29}	T_{28}, T_3, T_{29}	No flights after dark
$P_{2S4}137$	T_{29}	T_{21}, T_5, T_{29}	
$P_{2S4}138$	T_{29}	T_{21}, T_3, T_{29}	
$P_{2S4}139$	T_{29}	T_5, T_3, T_{29}	No flights after dark
$P_{2S4}140$	T_{29}	$T_{30}, T_{28}, T_{21}, T_{29}$	
$P_{2S4}141$	T_{29}	$T_{30}, T_{28}, T_5, T_{29}$	No flights after dark
$P_{2S4}142$	T_{29}	$T_{30}, T_{28}, T_3, T_{29}$	No flights after dark
$P_{2S4}143$	T_{29}	$T_{30}, T_{21}, T_5, T_{29}$	
$P_{2S4}144$	T_{29}	$T_{30}, T_{21}, T_3, T_{29}$	
$P_{2S4}145$	T_{29}	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}146$	T_{29}	$T_{28}, T_{21}, T_5, T_{29}$	
$P_{2S4}147$	T_{29}	$T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}148$	T_{29}	T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}149$	T_{29}	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}150$	T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_{29}$	
$P_{2S4}151$	T_{29}	$T_{30}, T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}152$	T_{29}	$T_{30}, T_{28}, T_5, T_3, T_{29}$	No flights after dark

Table G.5: Scenario #4 portfolios and their technologies (continued)

Portfolios	Year 30 to Year 10	Year 10 to Year 130	Observations
$P_{2S4}153$	T_{29}	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}154$	T_{29}	T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}155$	T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}156$	T_{30}, T_{21}	T_{30}, T_{28}, T_{21}	
$P_{2S4}157$	T_{30}, T_{21}	T_{30}, T_{21}, T_5	
$P_{2S4}158$	T_{30}, T_{21}	T_{30}, T_{21}, T_3	
$P_{2S4}159$	T_{30}, T_{21}	T_{30}, T_{21}, T_{29}	
$P_{2S4}160$	T_{30}, T_{21}	T_{30}, T_{28}, T_{21}, T_5	
$P_{2S4}161$	T_{30}, T_{21}	T_{30}, T_{28}, T_{21}, T_3	
$P_{2S4}162$	T_{30}, T_{21}	T_{30}, T_{28}, T_{21}, T_{29}	
$P_{2S4}163$	T_{30}, T_{21}	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}164$	T_{30}, T_{21}	T_{30}, T_{21}, T_5, T_{29}	
$P_{2S4}165$	T_{30}, T_{21}	T_{30}, T_{21}, T_3, T_{29}	
$P_{2S4}166$	T_{30}, T_{21}	T_{30}, T_{28}, T_{21}, T_5, T_3	
$P_{2S4}167$	T_{30}, T_{21}	T_{30}, T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}168$	T_{30}, T_{21}	T_{30}, T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}169$	T_{30}, T_{21}	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}170$	T_{30}, T_{21}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}171$	T_{30}, T_5	T_{30}, T_{28}, T_5	No flights after dark
$P_{2S4}172$	T_{30}, T_5	T_{30}, T_{21}, T_5	
$P_{2S4}173$	T_{30}, T_5	T_{30}, T_5, T_3	No flights after dark
$P_{2S4}174$	T_{30}, T_5	T_{30}, T_5, T_{29}	No flights after dark
$P_{2S4}175$	T_{30}, T_5	T_{30}, T_{28}, T_{21}, T_5	
$P_{2S4}176$	T_{30}, T_5	T_{30}, T_{28}, T_5, T_3	No flights after dark
$P_{2S4}177$	T_{30}, T_5	T_{30}, T_{28}, T_5, T_{29}	No flights after dark
$P_{2S4}178$	T_{30}, T_5	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}179$	T_{30}, T_5	T_{30}, T_{21}, T_5, T_{29}	
$P_{2S4}180$	T_{30}, T_5	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}181$	T_{30}, T_5	T_{30}, T_{28}, T_{21}, T_5, T_3	
$P_{2S4}182$	T_{30}, T_5	T_{30}, T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}183$	T_{30}, T_5	T_{30}, T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}184$	T_{30}, T_5	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}185$	T_{30}, T_5	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}186$	T_{30}, T_3	T_{30}, T_{28}, T_3	No flights after dark
$P_{2S4}187$	T_{30}, T_3	T_{30}, T_{21}, T_3	
$P_{2S4}188$	T_{30}, T_3	T_{30}, T_5, T_3	No flights after dark
$P_{2S4}189$	T_{30}, T_3	T_{30}, T_3, T_{29}	No flights after dark
$P_{2S4}190$	T_{30}, T_3	T_{30}, T_{28}, T_{21}, T_3	
$P_{2S4}191$	T_{30}, T_3	T_{30}, T_{28}, T_5, T_3	No flights after dark
$P_{2S4}192$	T_{30}, T_3	T_{30}, T_{28}, T_3, T_{29}	No flights after dark
$P_{2S4}193$	T_{30}, T_3	T_{30}, T_{21}, T_5, T_3	

Table G.6: Scenario #4 portfolios and their technologies (continued)

Portfolios	Year 30 to Year 10	Year 10 to Year 130	Observations
$P_{2S4}194$	T_{30}, T_3	T_{30}, T_{21}, T_3, T_{29}	
$P_{2S4}195$	T_{30}, T_3	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}196$	T_{30}, T_3	T_{30}, T_{28}, T_{21}, T_5, T_3	
$P_{2S4}197$	T_{30}, T_3	T_{30}, T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}198$	T_{30}, T_3	T_{30}, T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}199$	T_{30}, T_3	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}200$	T_{30}, T_3	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}201$	T_{30}, T_{29}	T_{30}, T_{28}, T_{29}	No flights after dark
$P_{2S4}202$	T_{30}, T_{29}	T_{30}, T_{21}, T_{29}	
$P_{2S4}203$	T_{30}, T_{29}	T_{30}, T_5, T_{29}	No flights after dark
$P_{2S4}204$	T_{30}, T_{29}	T_{30}, T_3, T_{29}	No flights after dark
$P_{2S4}205$	T_{30}, T_{29}	T_{30}, T_{28}, T_{21}, T_{29}	
$P_{2S4}206$	T_{30}, T_{29}	T_{30}, T_{28}, T_5, T_{29}	No flights after dark
$P_{2S4}207$	T_{30}, T_{29}	T_{30}, T_{28}, T_3, T_{29}	No flights after dark
$P_{2S4}208$	T_{30}, T_{29}	T_{30}, T_{21}, T_5, T_{29}	
$P_{2S4}209$	T_{30}, T_{29}	T_{30}, T_{21}, T_3, T_{29}	
$P_{2S4}210$	T_{30}, T_{29}	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}211$	T_{30}, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}212$	T_{30}, T_{29}	T_{30}, T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}213$	T_{30}, T_{29}	T_{30}, T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}214$	T_{30}, T_{29}	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}215$	T_{30}, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}216$	T_{21}, T_5	T_{30}, T_{21}, T_5	
$P_{2S4}217$	T_{21}, T_5	T_{28}, T_{21}, T_5	
$P_{2S4}218$	T_{21}, T_5	T_{21}, T_5, T_3	
$P_{2S4}219$	T_{21}, T_5	T_{21}, T_5, T_{29}	
$P_{2S4}220$	T_{21}, T_5	T_{30}, T_{28}, T_{21}, T_5	
$P_{2S4}221$	T_{21}, T_5	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}222$	T_{21}, T_5	T_{30}, T_{21}, T_5, T_{29}	
$P_{2S4}223$	T_{21}, T_5	T_{28}, T_{21}, T_5, T_3	
$P_{2S4}224$	T_{21}, T_5	T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}225$	T_{21}, T_5	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}226$	T_{21}, T_5	T_{30}, T_{28}, T_{21}, T_5, T_3	
$P_{2S4}227$	T_{21}, T_5	T_{30}, T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}228$	T_{21}, T_5	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}229$	T_{21}, T_5	T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}230$	T_{21}, T_5	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}231$	T_{21}, T_3	T_{30}, T_{21}, T_3	
$P_{2S4}232$	T_{21}, T_3	T_{28}, T_{21}, T_3	
$P_{2S4}233$	T_{21}, T_3	T_{21}, T_5, T_3	
$P_{2S4}234$	T_{21}, T_3	T_{21}, T_3, T_{29}	

Table G.7: Scenario #4 portfolios and their technologies (continued)

Portfolios	Year 30 to Year 10	Year 10 to Year 130	Observations
$P_{2S4}235$	T_{21}, T_3	T_{30}, T_{28}, T_{21}, T_3	
$P_{2S4}236$	T_{21}, T_3	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}237$	T_{21}, T_3	T_{30}, T_{21}, T_3, T_{29}	
$P_{2S4}238$	T_{21}, T_3	T_{28}, T_{21}, T_5, T_3	
$P_{2S4}239$	T_{21}, T_3	T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}240$	T_{21}, T_3	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}241$	T_{21}, T_3	T_{30}, T_{28}, T_{21}, T_5, T_3	
$P_{2S4}242$	T_{21}, T_3	T_{30}, T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}243$	T_{21}, T_3	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}244$	T_{21}, T_3	T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}245$	T_{21}, T_3	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}246$	T_{21}, T_{29}	T_{30}, T_{21}, T_{29}	
$P_{2S4}247$	T_{21}, T_{29}	T_{28}, T_{21}, T_{29}	
$P_{2S4}248$	T_{21}, T_{29}	T_{21}, T_5, T_{29}	
$P_{2S4}249$	T_{21}, T_{29}	T_{21}, T_3, T_{29}	
$P_{2S4}250$	T_{21}, T_{29}	T_{30}, T_{28}, T_{21}, T_{29}	
$P_{2S4}251$	T_{21}, T_{29}	T_{30}, T_{21}, T_5, T_{29}	
$P_{2S4}252$	T_{21}, T_{29}	T_{30}, T_{21}, T_3, T_{29}	
$P_{2S4}253$	T_{21}, T_{29}	T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}254$	T_{21}, T_{29}	T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}255$	T_{21}, T_{29}	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}256$	T_{21}, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}257$	T_{21}, T_{29}	T_{30}, T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}258$	T_{21}, T_{29}	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}259$	T_{21}, T_{29}	T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}260$	T_{21}, T_{29}	T_{290}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}261$	T_5, T_3	T_{30}, T_5, T_3	No flights after dark
$P_{2S4}262$	T_5, T_3	T_{28}, T_5, T_3	No flights after dark
$P_{2S4}263$	T_5, T_3	T_{21}, T_5, T_3	
$P_{2S4}264$	T_5, T_3	T_5, T_3, T_{29}	No flights after dark
$P_{2S4}265$	T_5, T_3	T_{30}, T_{28}, T_5, T_3	No flights after dark
$P_{2S4}266$	T_5, T_3	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}267$	T_5, T_3	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}268$	T_5, T_3	T_{28}, T_{21}, T_5, T_3	
$P_{2S4}269$	T_5, T_3	T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}270$	T_5, T_3	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}271$	T_5, T_3	T_{30}, T_{28}, T_{21}, T_5, T_3	
$P_{2S4}272$	T_5, T_3	T_{30}, T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}273$	T_5, T_3	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}274$	T_5, T_3	T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}275$	T_5, T_3	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	

Table G.8: Scenario #4 portfolios and their technologies (continued)

Portfolios	Year 30 to Year 10	Year 10 to Year 130	Observations
$P_{2S4}276$	T_5, T_{29}	T_{30}, T_5, T_{29}	No flights after dark
$P_{2S4}277$	T_5, T_{29}	T_{28}, T_5, T_{29}	No flights after dark
$P_{2S4}278$	T_5, T_{29}	T_{21}, T_5, T_{29}	
$P_{2S4}279$	T_5, T_{29}	T_5, T_3, T_{29}	No flights after dark
$P_{2S4}280$	T_5, T_{29}	T_{30}, T_{28}, T_5, T_{29}	No flights after dark
$P_{2S4}281$	T_5, T_{29}	T_{30}, T_{21}, T_5, T_{29}	
$P_{2S4}282$	T_5, T_{29}	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}283$	T_5, T_{29}	T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}284$	T_5, T_{29}	T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}285$	T_5, T_{29}	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}286$	T_5, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}287$	T_5, T_{29}	T_{30}, T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}288$	T_5, T_{29}	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}289$	T_5, T_{29}	T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}290$	T_5, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}291$	T_3, T_{29}	T_{30}, T_3, T_{29}	No flights after dark
$P_{2S4}292$	T_3, T_{29}	T_{28}, T_3, T_{29}	No flights after dark
$P_{2S4}293$	T_3, T_{29}	T_{21}, T_3, T_{29}	
$P_{2S4}294$	T_3, T_{29}	T_5, T_3, T_{29}	No flights after dark No flights after dark
$P_{2S4}295$	T_3, T_{29}	T_{30}, T_{28}, T_3, T_{29}	No flights after dark
$P_{2S4}296$	T_3, T_{29}	T_{30}, T_{21}, T_3, T_{29}	
$P_{2S4}297$	T_3, T_{29}	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}298$	T_3, T_{29}	T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}299$	T_3, T_{29}	T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}300$	T_3, T_{29}	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}301$	T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_3, T_{29}	
$P_{2S4}302$	T_3, T_{29}	T_{30}, T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}303$	T_3, T_{29}	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}304$	T_3, T_{29}	T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}305$	T_3, T_{29}	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}306$	T_{30}, T_{21}, T_5	T_{30}, T_{28}, T_{21}, T_5	
$P_{2S4}307$	T_{30}, T_{21}, T_5	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}308$	T_{30}, T_{21}, T_5	T_{30}, T_{21}, T_5, T_{29}	
$P_{2S4}309$	T_{30}, T_{21}, T_5	T_{30}, T_{28}, T_{21}, T_5, T_3	
$P_{2S4}310$	T_{30}, T_{21}, T_5	T_{30}, T_{28}, T_{21}, T_5, T_{29}	
$P_{2S4}311$	T_{30}, T_{21}, T_5	T_{30}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}312$	T_{30}, T_{21}, T_5	T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}	
$P_{2S4}313$	T_{30}, T_{21}, T_3	T_{30}, T_{28}, T_{21}, T_3	
$P_{2S4}314$	T_{30}, T_{21}, T_3	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}315$	T_{30}, T_{21}, T_3	T_{30}, T_{21}, T_3, T_{29}	
$P_{2S4}316$	T_{30}, T_{21}, T_3	T_{30}, T_{28}, T_{21}, T_5, T_3	

Table G.9: Scenario #4 portfolios and their technologies (continued)

Portfolios	Year 30 to Year 10	Year 10 to Year 130	Observations
$P_{2S4}317$	T_{30}, T_{21}, T_3	$T_{30}, T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}318$	T_{30}, T_{21}, T_3	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}319$	T_{30}, T_{21}, T_3	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}320$	T_{30}, T_{21}, T_{29}	$T_{30}, T_{28}, T_{21}, T_{29}$	
$P_{2S4}321$	T_{30}, T_{21}, T_{29}	$T_{30}, T_{21}, T_5, T_{29}$	
$P_{2S4}322$	T_{30}, T_{21}, T_{29}	$T_{30}, T_{21}, T_3, T_{29}$	
$P_{2S4}323$	T_{30}, T_{21}, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_{29}$	
$P_{2S4}324$	T_{30}, T_{21}, T_{29}	$T_{30}, T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}325$	T_{30}, T_{21}, T_{29}	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}326$	T_{30}, T_{21}, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}327$	T_{30}, T_5, T_3	T_{30}, T_{28}, T_5, T_3	No flights after dark
$P_{2S4}328$	T_{30}, T_5, T_3	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}329$	T_{30}, T_5, T_3	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}330$	T_{30}, T_5, T_3	$T_{30}, T_{28}, T_{21}, T_5, T_3$	
$P_{2S4}331$	T_{30}, T_5, T_3	$T_{30}, T_{28}, T_5, T_3, T_{29}$	No flights after dark
$P_{2S4}332$	T_{30}, T_5, T_3	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}333$	T_{30}, T_5, T_3	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}334$	T_{30}, T_5, T_{29}	$T_{30}, T_{28}, T_5, T_{29}$	No flights after dark
$P_{2S4}335$	T_{30}, T_5, T_{29}	$T_{30}, T_{21}, T_5, T_{29}$	
$P_{2S4}336$	T_{30}, T_5, T_{29}	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}337$	T_{30}, T_5, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_{29}$	
$P_{2S4}338$	T_{30}, T_5, T_{29}	$T_{30}, T_{28}, T_5, T_3, T_{29}$	No flights after dark
$P_{2S4}339$	T_{30}, T_5, T_{29}	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}340$	T_{30}, T_5, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}341$	T_{30}, T_3, T_{29}	$T_{30}, T_{28}, T_3, T_{29}$	No flights after dark
$P_{2S4}342$	T_{30}, T_3, T_{29}	$T_{30}, T_{21}, T_3, T_{29}$	
$P_{2S4}343$	T_{30}, T_3, T_{29}	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}344$	T_{30}, T_3, T_{29}	$T_{30}, T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}345$	T_{30}, T_3, T_{29}	$T_{30}, T_{28}, T_5, T_3, T_{29}$	No flights after dark
$P_{2S4}346$	T_{30}, T_3, T_{29}	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}347$	T_{30}, T_3, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}348$	T_{21}, T_5, T_3	T_{30}, T_{21}, T_5, T_3	
$P_{2S4}349$	T_{21}, T_5, T_3	T_{28}, T_{21}, T_5, T_3	
$P_{2S4}350$	T_{21}, T_5, T_3	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}351$	T_{21}, T_5, T_3	$T_{30}, T_{28}, T_{21}, T_5, T_3$	
$P_{2S4}352$	T_{21}, T_5, T_3	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}353$	T_{21}, T_5, T_3	$T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}354$	T_{21}, T_5, T_3	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}355$	T_{21}, T_5, T_{29}	$T_{30}, T_{21}, T_5, T_{29}$	
$P_{2S4}356$	T_{21}, T_5, T_{29}	$T_{28}, T_{21}, T_5, T_{29}$	
$P_{2S4}357$	T_{21}, T_5, T_{29}	T_{21}, T_5, T_3, T_{29}	

Table G.10: Scenario #4 portfolios and their technologies (continued)

Portfolios	Year 30 to Year 10	Year 10 to Year 130	Observations
$P_{2S4}358$	T_{21}, T_5, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_{29}$	
$P_{2S4}359$	T_{21}, T_5, T_{29}	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}360$	T_{21}, T_5, T_{29}	$T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}361$	T_{21}, T_5, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}362$	T_{21}, T_3, T_{29}	$T_{30}, T_{21}, T_3, T_{29}$	
$P_{2S4}363$	T_{21}, T_3, T_{29}	$T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}364$	T_{21}, T_3, T_{29}	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}365$	T_{21}, T_3, T_{29}	$T_{30}, T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}366$	T_{21}, T_3, T_{29}	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}367$	T_{21}, T_3, T_{29}	$T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}368$	T_{21}, T_3, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}369$	T_5, T_3, T_{29}	T_{30}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}370$	T_5, T_3, T_{29}	T_{28}, T_5, T_3, T_{29}	No flights after dark
$P_{2S4}371$	T_5, T_3, T_{29}	T_{21}, T_5, T_3, T_{29}	
$P_{2S4}372$	T_5, T_3, T_{29}	$T_{30}, T_{28}, T_5, T_3, T_{29}$	No flights after dark
$P_{2S4}373$	T_5, T_3, T_{29}	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}374$	T_5, T_3, T_{29}	$T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}375$	T_5, T_3, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}376$	T_{30}, T_{21}, T_5, T_3	$T_{30}, T_{28}, T_{21}, T_5, T_3$	
$P_{2S4}377$	T_{30}, T_{21}, T_5, T_3	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}378$	T_{30}, T_{21}, T_5, T_3	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}379$	$T_{30}, T_{21}, T_5, T_{29}$	$T_{30}, T_{28}, T_{21}, T_5, T_{29}$	
$P_{2S4}380$	$T_{30}, T_{21}, T_5, T_{29}$	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}381$	$T_{30}, T_{21}, T_5, T_{29}$	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}382$	$T_{30}, T_{21}, T_3, T_{29}$	$T_{30}, T_{28}, T_{21}, T_3, T_{29}$	
$P_{2S4}383$	$T_{30}, T_{21}, T_3, T_{29}$	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}384$	$T_{30}, T_{21}, T_3, T_{29}$	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}385$	T_{30}, T_5, T_3, T_{29}	$T_{30}, T_{28}, T_5, T_3, T_{29}$	
$P_{2S4}386$	T_{30}, T_5, T_3, T_{29}	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}387$	T_{30}, T_5, T_3, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}388$	T_{21}, T_5, T_3, T_{29}	$T_{30}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}389$	T_{21}, T_5, T_3, T_{29}	$T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}390$	T_{21}, T_5, T_3, T_{29}	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	
$P_{2S4}391$	$T_{30}, T_{21}, T_5, T_3, T_{29}$	$T_{30}, T_{28}, T_{21}, T_5, T_3, T_{29}$	

G.2 *Option Value Calculations for Airport #2 Portfolios*

Table G.11: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #2 portfolios (round-up values)

Portfolios	S ($M\$$)	X ($M\$$)	Passive NPV ($M\$$)	Value of Flexibility ($M\$$)	eNPV ($M\$$)
P_1	4.189	1.000	2.904	3.774	6.677
P_2	-0.419	0.078	-3.189	n.a.	n.a.
P_3	-0.746	4.305	-6.776	n.a.	n.a.
P_4	-0.515	1.461	-4.347	n.a.	n.a.
P_5	4.526	0.500	3.766	4.277	8.043
P_6	-1.136	1.078	-4.978	n.a.	n.a.
P_7	-1.457	5.305	-8.556	n.a.	n.a.
P_8	-1.234	2.461	-6.138	n.a.	n.a.
P_9	3.802	1.500	1.968	3.268	5.236
P_{10}	3.911	4.384	0.008	2.882	2.890
P_{11}	4.146	1.540	2.444	3.587	6.032
P_{12}	-0.796	0.578	-4.110	n.a.	n.a.
P_{13}	-1.178	5.766	-8.486	n.a.	n.a.
P_{14}	-1.126	4.805	-7.703	n.a.	n.a.
P_{15}	4.093	1.961	2.056	3.441	5.497
P_{16}	3.205	5.384	-1.764	2.168	0.404
P_{17}	3.438	2.540	0.669	2.723	3.391
P_{18}	-1.515	1.578	-5.903	n.a.	n.a.
P_{19}	-1.892	6.766	-10.269	n.a.	n.a.
P_{20}	-1.845	5.805	-9.493	n.a.	n.a.
P_{21}	3.380	2.961	0.273	2.604	2.877
P_{22}	3.482	5.845	-1.696	2.356	0.660
P_{23}	3.540	4.884	-0.904	2.502	1.599
P_{24}	-1.229	2.040	-5.821	n.a.	n.a.
P_{25}	3.439	6.266	-2.069	2.283	0.213
P_{26}	2.769	6.845	-3.479	1.699	-1.779
P_{27}	2.824	5.884	-2.692	1.813	-0.879
P_{28}	-1.947	3.040	-7.610	n.a.	n.a.
P_{29}	2.715	7.266	-3.868	1.629	-2.238
P_{30}	3.112	6.345	-2.608	2.009	-0.599
P_{31}	-2.611	7.345	-11.751	n.a.	n.a.

Table G.12: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #3 portfolios (round-up values)

Portfolios	S ($M\$$)	X ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_1	-0.090	1.000	-3.602	n.a.	n.a.
P_2	-0.087	1.000	-3.596	n.a.	n.a.
P_3	1.521	0.078	0.337	1.503	1.840
P_4	-0.061	4.305	-5.192	n.a.	n.a.
P_5	-0.014	1.461	-3.667	n.a.	n.a.
P_6	0.006	0.500	-3.144	0.003	-3.141
P_7	-0.296	2.000	-4.546	n.a.	n.a.
P_8	1.312	1.078	-0.615	1.212	0.597
P_9	-0.272	5.305	-6.148	n.a.	n.a.
P_{10}	-0.219	2.461	-4.611	n.a.	n.a.
P_{11}	-0.205	1.500	-4.099	n.a.	n.a.
P_{12}	1.314	1.078	-0.610	1.214	0.605
P_{13}	-0.270	5.305	-6.145	n.a.	n.a.
P_{14}	-0.220	2.461	-4.613	n.a.	n.a.
P_{15}	-0.201	1.500	-4.092	n.a.	n.a.
P_{16}	1.335	4.384	-2.218	1.126	-1.092
P_{17}	1.388	1.540	-0.681	1.263	0.581
P_{18}	1.406	0.578	-0.160	1.336	1.175
P_{19}	-0.193	5.766	-6.208	n.a.	n.a.
P_{20}	-0.176	4.805	-5.691	n.a.	n.a.
P_{21}	-0.124	1.961	-4.156	n.a.	n.a.
P_{22}	1.106	2.078	-1.560	0.974	-0.586
P_{23}	-0.476	6.305	-7.089	n.a.	n.a.
P_{24}	-0.425	3.461	-5.556	n.a.	n.a.
P_{25}	-0.409	2.500	-5.041	n.a.	n.a.
P_{26}	1.130	5.384	-3.160	0.920	-2.240
P_{27}	1.178	2.540	-1.635	1.028	-0.607
P_{28}	1.198	1.578	-1.111	1.079	-0.032
P_{29}	-0.402	6.766	-7.159	n.a.	n.a.
P_{30}	-0.382	5.805	-6.636	n.a.	n.a.
P_{31}	-0.333	2.961	-5.107	n.a.	n.a.
P_{32}	1.131	5.384	-3.158	0.921	-2.237

Table G.13: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #3 portfolios (round-up values) (continued)

Portfolios	S ($M\$$)	X ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{33}	1.179	2.540	-1.633	1.028	-0.605
P_{34}	1.198	1.578	-1.111	1.079	-0.032
P_{35}	-0.401	6.766	-7.158	n.a.	n.a.
P_{36}	-0.381	5.805	-6.635	n.a.	n.a.
P_{37}	-0.333	2.961	-5.107	n.a.	n.a.
P_{38}	1.205	5.845	-3.230	0.979	-2.251
P_{39}	1.223	4.884	-2.711	1.013	-1.698
P_{40}	1.277	2.040	-1.171	1.137	-0.034
P_{41}	-0.309	6.266	-6.709	n.a.	n.a.
P_{42}	0.923	6.384	-4.107	0.722	-3.385
P_{43}	0.975	3.540	-2.574	0.815	-1.759
P_{44}	0.989	2.578	-2.062	0.850	-1.211
P_{45}	-0.607	7.766	-8.103	n.a.	n.a.
P_{46}	-0.592	6.805	-7.589	n.a.	n.a.
P_{47}	-0.538	3.961	-6.050	n.a.	n.a.
P_{48}	1.005	6.845	-4.162	0.787	-3.375
P_{49}	1.016	5.884	-3.657	0.810	-2.846
P_{50}	1.065	3.040	-2.129	0.909	-1.221
P_{51}	-0.512	7.266	-7.649	n.a.	n.a.
P_{52}	1.002	6.845	-4.169	0.784	-3.384
P_{53}	1.017	5.884	-3.654	0.811	-2.843
P_{54}	1.067	3.040	-2.125	0.910	-1.215
P_{55}	-0.516	7.266	-7.656	n.a.	n.a.
P_{56}	1.097	6.345	-3.713	0.875	-2.838
P_{57}	0.793	7.845	-5.121	0.592	-4.528
P_{58}	0.811	6.884	-4.601	0.618	-3.983
P_{59}	0.863	4.040	-3.065	0.704	-2.361
P_{60}	-0.718	8.266	-8.593	n.a.	n.a.
P_{61}	0.887	7.345	-4.666	0.679	-3.988
P_{62}	0.887	7.345	-4.666	0.679	-3.987
P_{63}	0.680	8.345	-5.613	0.494	-5.120

Table G.14: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_1	-3.075	1.000	-1.037	2.000	-7.676	n.a	n.a
P_2	0.856	1.000	2.433	1.078	-3.745	1.759	-1.986
P_3	-4.677	1.000	-0.986	5.305	-9.279	n.a	n.a
P_4	-3.140	1.000	-0.871	2.461	-7.742	n.a	n.a
P_5	-2.629	1.000	-0.840	1.500	-7.230	n.a	n.a
P_6	-0.089	1.000	1.989	2.078	-4.690	0.481	-4.209
P_7	-5.618	1.000	-1.426	6.305	-10.220	n.a	n.a
P_8	-4.085	1.000	-1.316	3.461	-8.686	n.a	n.a
P_9	-3.570	1.000	-1.282	2.500	-8.171	n.a	n.a
P_{10}	-1.689	1.000	2.042	5.384	-6.290	n.a	n.a
P_{11}	-0.164	1.000	2.145	2.540	-4.765	0.504	-4.261
P_{12}	0.360	1.000	2.187	1.578	-4.241	1.050	-3.192
P_{13}	-5.689	1.000	-1.266	6.766	-10.290	n.a	n.a
P_{14}	-5.165	1.000	-1.224	5.805	-9.767	n.a	n.a
P_{15}	-3.636	1.000	-1.117	2.961	-8.238	n.a	n.a
P_{16}	-2.636	1.000	1.595	6.384	-7.237	n.a	n.a
P_{17}	-1.103	1.000	1.706	3.540	-5.704	n.a	n.a
P_{18}	-0.591	1.000	1.737	2.578	-5.192	n.a	n.a
P_{19}	-6.632	1.000	-1.709	7.766	-11.233	n.a	n.a
P_{20}	-6.119	1.000	-1.677	6.805	-10.720	n.a	n.a
P_{21}	-4.579	1.000	-1.560	3.961	-9.180	n.a	n.a
P_{22}	-2.691	1.000	1.771	6.845	-7.292	n.a	n.a
P_{23}	-2.186	1.000	1.795	5.884	-6.787	n.a	n.a
P_{24}	-0.658	1.000	1.900	3.040	-5.260	n.a	n.a
P_{25}	-6.178	1.000	-1.505	7.266	-10.779	n.a	n.a
P_{26}	-3.650	1.000	1.312	7.845	-8.251	n.a	n.a
P_{27}	-3.130	1.000	1.352	6.884	-7.731	n.a	n.a
P_{28}	-1.594	1.000	1.465	4.040	-6.195	n.a	n.a

Table G.15: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{29}	-7.122	1.000	-1.949	8.266	-11.723	n.a	n.a
P_{30}	-3.195	1.000	1.517	7.345	-7.796	n.a	n.a
P_{31}	-4.142	1.000	1.070	8.345	-8.744	n.a	n.a
P_{32}	5.561	0.078	3.052	1.078	1.637	7.577	9.215
P_{33}	5.566	0.078	3.057	1.078	1.642	7.586	9.228
P_{34}	3.958	0.078	3.103	4.384	0.035	5.658	5.692
P_{35}	5.494	0.078	3.216	1.540	1.571	7.559	9.130
P_{36}	6.016	0.078	3.257	0.578	2.092	8.287	10.379
P_{37}	4.616	0.078	2.608	2.078	0.693	6.203	6.895
P_{38}	3.016	0.078	2.661	5.384	-0.908	4.341	3.433
P_{39}	4.541	0.078	2.763	2.540	0.617	6.190	6.807
P_{40}	5.065	0.078	2.806	1.578	1.141	6.840	7.981
P_{41}	3.018	0.078	2.663	5.384	-0.906	4.344	3.439
P_{42}	4.543	0.078	2.765	2.540	0.619	6.192	6.811
P_{43}	5.065	0.078	2.806	1.578	1.141	6.839	7.980
P_{44}	2.946	0.078	2.821	5.845	-0.978	4.363	3.385
P_{45}	3.465	0.078	2.860	4.884	-0.459	4.945	4.486
P_{46}	5.005	0.078	2.977	2.040	1.081	6.853	7.934
P_{47}	2.069	0.078	2.214	6.384	-1.855	3.121	1.266
P_{48}	3.602	0.078	2.324	3.540	-0.322	4.844	4.523
P_{49}	4.114	0.078	2.356	2.578	0.190	5.475	5.665
P_{50}	2.014	0.078	2.389	6.845	-1.910	3.168	1.258
P_{51}	2.519	0.078	2.414	5.884	-1.405	3.694	2.290
P_{52}	4.047	0.078	2.519	3.040	0.123	5.474	5.597
P_{53}	2.008	0.078	2.383	6.845	-1.916	3.158	1.242
P_{54}	2.521	0.078	2.416	5.884	-1.402	3.698	2.295
P_{55}	4.051	0.078	2.523	3.040	0.127	5.481	5.608
P_{56}	2.463	0.078	2.588	6.345	-1.461	3.738	2.277

Table G.16: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 (M\$)	X_1 (M\$)	S_2 (M\$)	X_2 (M\$)	**Passive NPV** (M\$)	**Value of Flexibility** (M\$)	**eNPV** (M\$)
P_{57}	1.055	0.078	1.931	7.845	-2.868	1.936	-0.932
P_{58}	1.575	0.078	1.970	6.884	-2.348	2.481	0.133
P_{59}	3.111	0.078	2.083	4.040	-0.813	4.135	3.322
P_{60}	1.510	0.078	2.136	7.345	-2.414	2.512	0.098
P_{61}	1.510	0.078	2.136	7.345	-2.414	2.512	0.098
P_{62}	0.563	0.078	1.689	8.345	-3.361	1.306	-2.055
P_{63}	5.561	0.078	3.052	1.078	1.637	n.a	n.a
P_{64}	5.566	0.078	3.057	1.078	1.642	n.a	n.a
P_{65}	3.958	0.078	3.103	4.384	0.035	n.a	n.a
P_{66}	5.494	0.078	3.216	1.540	1.571	n.a	n.a
P_{67}	6.016	0.078	3.257	0.578	2.092	n.a	n.a
P_{68}	4.616	0.078	2.608	2.078	0.693	n.a	n.a
P_{69}	3.016	0.078	2.661	5.384	-0.908	n.a	n.a
P_{70}	4.541	0.078	2.763	2.540	0.617	n.a	n.a
P_{71}	5.065	0.078	2.806	1.578	1.141	n.a	n.a
P_{72}	3.018	0.078	2.663	5.384	-0.906	n.a	n.a
P_{73}	4.543	0.078	2.765	2.540	0.619	n.a	n.a
P_{74}	5.065	0.078	2.806	1.578	1.141	n.a	n.a
P_{75}	2.946	0.078	2.821	5.845	-0.978	n.a	n.a
P_{76}	3.465	0.078	2.860	4.884	-0.459	n.a	n.a
P_{77}	5.005	0.078	2.977	2.040	1.081	n.a	n.a
P_{78}	2.069	0.078	2.214	6.384	-1.855	n.a	n.a
P_{79}	3.602	0.078	2.324	3.540	-0.322	n.a	n.a
P_{80}	4.114	0.078	2.356	2.578	0.190	n.a	n.a
P_{81}	2.014	0.078	2.389	6.845	-1.910	n.a	n.a
P_{82}	2.519	0.078	2.414	5.884	-1.405	n.a	n.a
P_{83}	4.047	0.078	2.519	3.040	0.123	n.a	n.a
P_{84}	2.008	0.078	2.383	6.845	-1.916	n.a	n.a

Table G.17: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{85}	2.521	0.078	2.416	5.884	-1.402	n.a	n.a
P_{86}	4.051	0.078	2.523	3.040	0.127	n.a	n.a
P_{87}	2.463	0.078	2.588	6.345	-1.461	n.a	n.a
P_{88}	1.055	0.078	1.931	7.845	-2.868	n.a	n.a
P_{89}	1.575	0.078	1.970	6.884	-2.348	n.a	n.a
P_{90}	3.111	0.078	2.083	4.040	-0.813	n.a	n.a
P_{91}	1.510	0.078	2.136	7.345	-2.414	n.a	n.a
P_{92}	1.510	0.078	2.136	7.345	-2.414	n.a	n.a
P_{93}	0.563	0.078	1.689	8.345	-3.361	n.a	n.a
P_{94}	-2.721	1.461	-0.694	2.461	-7.661	n.a	n.a
P_{95}	-2.723	1.461	-0.695	2.461	-7.663	n.a	n.a
P_{96}	1.209	1.461	2.775	1.540	-3.732	1.992	-1.740
P_{97}	-4.318	1.461	-0.637	5.766	-9.258	n.a	n.a
P_{98}	-2.266	1.461	-0.489	1.961	-7.206	n.a	n.a
P_{99}	-3.666	1.461	-1.138	3.461	-8.606	n.a	n.a
P_{100}	0.255	1.461	2.322	2.540	-4.685	0.683	-4.001
P_{101}	-5.270	1.461	-1.088	6.766	-10.210	n.a	n.a
P_{102}	-3.217	1.461	-0.940	2.961	-8.157	n.a	n.a
P_{103}	0.257	1.461	2.324	2.540	-4.683	0.686	-3.998
P_{104}	-5.268	1.461	-1.087	6.766	-10.208	n.a	n.a
P_{105}	-3.217	1.461	-0.940	2.961	-8.157	n.a	n.a
P_{106}	-1.340	1.461	2.380	5.845	-6.281	n.a	n.a
P_{107}	0.719	1.461	2.536	2.040	-4.221	1.291	-2.930
P_{108}	-4.819	1.461	-0.888	6.266	-9.759	n.a	n.a
P_{109}	-0.684	1.461	1.883	3.540	-5.624	n.a	n.a
P_{110}	-6.213	1.461	-1.531	7.766	-11.153	n.a	n.a
P_{111}	-4.160	1.461	-1.382	3.961	-9.100	n.a	n.a
P_{112}	-2.272	1.461	1.948	6.845	-7.212	n.a	n.a

Table G.18: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{113}	-0.239	1.461	2.078	3.040	-5.179	0.069	-5.111
P_{114}	-5.759	1.461	-1.328	7.266	-10.699	n.a	n.a
P_{115}	-1.765	1.461	1.975	5.884	-6.705	n.a	n.a
P_{116}	-0.235	1.461	2.082	3.040	-5.175	0.075	-5.100
P_{117}	-5.766	1.461	-1.334	7.266	-10.706	n.a	n.a
P_{118}	-1.823	1.461	2.147	6.345	-6.763	n.a	n.a
P_{119}	-3.231	1.461	1.490	7.845	-8.171	n.a	n.a
P_{120}	-1.175	1.461	1.642	4.040	-6.115	n.a	n.a
P_{121}	-6.703	1.461	-1.772	8.266	-11.643	n.a	n.a
P_{122}	-2.776	1.461	1.694	7.345	-7.716	n.a	n.a
P_{123}	-2.776	1.461	1.695	7.345	-7.716	n.a	n.a
P_{124}	-3.723	1.461	1.247	8.345	-8.663	n.a	n.a
P_{125}	-2.130	0.500	-0.640	1.500	-6.364	n.a	n.a
P_{126}	-2.123	0.500	-0.633	1.500	-6.356	n.a	n.a
P_{127}	1.809	0.500	2.838	0.578	-2.425	3.387	0.962
P_{128}	-3.722	0.500	-0.578	4.805	-7.956	n.a	n.a
P_{129}	-2.187	0.500	-0.466	1.961	-6.421	n.a	n.a
P_{130}	-3.072	0.500	-1.081	2.500	-7.305	n.a	n.a
P_{131}	0.858	0.500	2.387	1.578	-3.376	2.023	-1.352
P_{132}	-4.667	0.500	-1.023	5.805	-8.901	n.a	n.a
P_{133}	-3.138	0.500	-0.917	2.961	-7.372	n.a	n.a
P_{134}	0.858	0.500	2.387	1.578	-3.376	2.023	-1.352
P_{135}	-4.666	0.500	-1.022	5.805	-8.899	n.a	n.a
P_{136}	-3.138	0.500	-0.917	2.961	-7.372	n.a	n.a
P_{137}	-0.741	0.500	2.441	4.884	-4.975	0.510	-4.465
P_{138}	0.798	0.500	2.558	2.040	-3.435	2.040	-1.395
P_{139}	-4.740	0.500	-0.865	6.266	-8.973	n.a	n.a
P_{140}	-0.092	0.500	1.937	2.578	-4.326	0.771	-3.555

Table G.19: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{141}	-5.620	0.500	-1.476	6.805	-9.854	n.a	n.a
P_{142}	-4.081	0.500	-1.359	3.961	-8.314	n.a	n.a
P_{143}	-1.687	0.500	1.995	5.884	-5.921	n.a	n.a
P_{144}	-0.160	0.500	2.100	3.040	-4.394	0.806	-3.587
P_{145}	-5.680	0.500	-1.305	7.266	-9.913	n.a	n.a
P_{146}	-1.685	0.500	1.998	5.884	-5.919	n.a	n.a
P_{147}	-0.156	0.500	2.104	3.040	-4.389	0.812	-3.577
P_{148}	-5.687	0.500	-1.312	7.266	-9.920	n.a	n.a
P_{149}	-1.744	0.500	2.170	6.345	-5.978	n.a	n.a
P_{150}	-2.631	0.500	1.552	6.884	-6.865	n.a	n.a
P_{151}	-1.096	0.500	1.665	4.040	-5.329	n.a	n.a
P_{152}	-6.624	0.500	-1.749	8.266	-10.858	n.a	n.a
P_{153}	-2.697	0.500	1.717	7.345	-6.930	n.a	n.a
P_{154}	-2.697	0.500	1.717	7.345	-6.930	n.a	n.a
P_{155}	-3.644	0.500	1.270	8.345	-7.878	n.a	n.a
P_{156}	3.563	1.078	2.208	2.078	-1.096	4.184	3.088
P_{157}	1.963	1.078	2.261	5.384	-2.696	2.406	-0.290
P_{158}	3.488	1.078	2.364	2.540	-1.171	4.171	3.000
P_{159}	4.012	1.078	2.407	1.578	-0.647	4.821	4.174
P_{160}	1.016	1.078	1.814	6.384	-3.643	1.190	-2.453
P_{161}	2.549	1.078	1.925	3.540	-2.110	2.826	0.716
P_{162}	3.061	1.078	1.956	2.578	-1.598	3.456	1.858
P_{163}	0.961	1.078	1.990	6.845	-3.698	1.239	-2.459
P_{164}	1.466	1.078	2.015	5.884	-3.193	1.760	-1.432
P_{165}	2.994	1.078	2.119	3.040	-1.665	3.456	1.790
P_{166}	0.002	1.078	1.532	7.845	-4.656	0.069	-4.588
P_{167}	0.522	1.078	1.571	6.884	-4.137	0.558	-3.578
P_{168}	2.058	1.078	1.684	4.040	-2.601	2.167	-0.433

Table G.20: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	Passive NPV ($M\$$)	Value of Flexibility ($M\$$)	eNPV ($M\$$)
P_{169}	0.457	1.078	1.736	7.345	-4.202	0.594	-3.608
P_{170}	-0.490	1.078	1.289	8.345	-5.149	n.a	n.a
P_{171}	-6.584	5.305	-1.817	6.305	-14.350	n.a	n.a
P_{172}	-2.655	5.305	1.651	5.384	-10.420	n.a	n.a
P_{173}	-6.654	5.305	-1.657	6.766	-14.420	n.a	n.a
P_{174}	-6.131	5.305	-1.615	5.805	-13.897	n.a	n.a
P_{175}	-3.602	5.305	1.204	6.384	-11.368	n.a	n.a
P_{176}	-7.597	5.305	-2.100	7.766	-15.363	n.a	n.a
P_{177}	-7.084	5.305	-2.068	6.805	-14.850	n.a	n.a
P_{178}	-3.657	5.305	1.380	6.845	-11.423	n.a	n.a
P_{179}	-3.151	5.305	1.404	5.884	-10.917	n.a	n.a
P_{180}	-7.144	5.305	-1.896	7.266	-14.909	n.a	n.a
P_{181}	-4.615	5.305	0.921	7.845	-12.381	n.a	n.a
P_{182}	-4.095	5.305	0.961	6.884	-11.861	n.a	n.a
P_{183}	-8.088	5.305	-2.340	8.266	-15.853	n.a	n.a
P_{184}	-4.161	5.305	1.126	7.345	-11.926	n.a	n.a
P_{185}	-5.108	5.305	0.679	8.345	-12.874	n.a	n.a
P_{186}	-4.717	2.461	-1.537	3.461	-10.392	n.a	n.a
P_{187}	-0.796	2.461	1.923	2.540	-6.471	n.a	n.a
P_{188}	-6.321	2.461	-1.487	6.766	-11.996	n.a	n.a
P_{189}	-4.268	2.461	-1.339	2.961	-9.944	n.a	n.a
P_{190}	-1.735	2.461	1.484	3.540	-7.410	n.a	n.a
P_{191}	-7.264	2.461	-1.930	7.766	-12.939	n.a	n.a
P_{192}	-5.211	2.461	-1.781	3.961	-10.886	n.a	n.a
P_{193}	-3.323	2.461	1.549	6.845	-8.998	n.a	n.a
P_{194}	-1.290	2.461	1.679	3.040	-6.965	n.a	n.a
P_{195}	-6.810	2.461	-1.727	7.266	-12.485	n.a	n.a
P_{196}	-4.282	2.461	1.091	7.845	-9.957	n.a	n.a

Table G.21: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{197}	-2.226	2.461	1.243	4.040	-7.901	n.a	n.a
P_{198}	-7.754	2.461	-2.171	8.266	-13.429	n.a	n.a
P_{199}	-3.827	2.461	1.295	7.345	-9.502	n.a	n.a
P_{200}	-4.774	2.461	0.849	8.345	-10.449	n.a	n.a
P_{201}	-4.129	1.500	-1.482	2.500	-9.098	n.a	n.a
P_{202}	-0.200	1.500	1.987	1.578	-5.168	0.053	-5.115
P_{203}	-5.725	1.500	-1.424	5.805	-10.693	n.a	n.a
P_{204}	-4.196	1.500	-1.317	2.961	-9.164	n.a	n.a
P_{205}	-1.150	1.500	1.537	2.578	-6.119	n.a	n.a
P_{206}	-6.678	1.500	-1.877	6.805	-11.647	n.a	n.a
P_{207}	-5.138	1.500	-1.759	3.961	-10.107	n.a	n.a
P_{208}	-2.745	1.500	1.595	5.884	-7.714	n.a	n.a
P_{209}	-1.218	1.500	1.700	3.040	-6.186	n.a	n.a
P_{210}	-6.737	1.500	-1.705	7.266	-11.706	n.a	n.a
P_{211}	-3.689	1.500	1.152	6.884	-8.658	n.a	n.a
P_{212}	-2.153	1.500	1.265	4.040	-7.122	n.a	n.a
P_{213}	-7.682	1.500	-2.149	8.266	-12.650	n.a	n.a
P_{214}	-3.755	1.500	1.317	7.345	-8.723	n.a	n.a
P_{215}	-4.702	1.500	0.870	8.345	-9.670	n.a	n.a
P_{216}	2.051	4.384	2.270	5.384	-5.037	0.245	-4.792
P_{217}	2.053	4.384	2.272	5.384	-5.035	0.249	-4.786
P_{218}	1.981	4.384	2.430	5.845	-5.107	0.268	-4.840
P_{219}	2.501	4.384	2.469	4.884	-4.588	0.816	-3.772
P_{220}	1.104	4.384	1.823	6.384	-5.984	n.a	n.a
P_{221}	1.049	4.384	1.999	6.845	-6.039	n.a	n.a
P_{222}	1.555	4.384	2.023	5.884	-5.534	n.a	n.a
P_{223}	1.043	4.384	1.992	6.845	-6.045	n.a	n.a
P_{224}	1.557	4.384	2.025	5.884	-5.531	n.a	n.a

Table G.22: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{225}	1.498	4.384	2.198	6.345	-5.590	n.a	n.a
P_{226}	0.091	4.384	1.540	7.845	-6.997	n.a	n.a
P_{227}	0.611	4.384	1.580	6.884	-6.478	n.a	n.a
P_{228}	0.545	4.384	1.745	7.345	-6.543	n.a	n.a
P_{229}	0.545	4.384	1.745	7.345	-6.543	n.a	n.a
P_{230}	-0.402	4.384	1.298	8.345	-7.490	n.a	n.a
P_{231}	3.901	1.540	2.542	2.540	-1.097	4.396	3.300
P_{232}	3.903	1.540	2.543	2.540	-1.095	4.399	3.304
P_{233}	2.306	1.540	2.599	5.845	-2.692	2.619	-0.073
P_{234}	4.365	1.540	2.755	2.040	-0.633	5.059	4.427
P_{235}	2.962	1.540	2.103	3.540	-2.036	3.051	1.015
P_{236}	1.374	1.540	2.168	6.845	-3.624	1.427	-2.197
P_{237}	3.407	1.540	2.297	3.040	-1.591	3.681	2.090
P_{238}	1.368	1.540	2.161	6.845	-3.630	1.417	-2.213
P_{239}	3.411	1.540	2.301	3.040	-1.587	3.688	2.101
P_{240}	1.823	1.540	2.367	6.345	-3.175	1.996	-1.179
P_{241}	0.415	1.540	1.710	7.845	-4.582	0.209	-4.373
P_{242}	2.471	1.540	1.862	4.040	-2.527	2.360	-0.167
P_{243}	0.870	1.540	1.914	7.345	-4.128	0.775	-3.353
P_{244}	0.870	1.540	1.914	7.345	-4.128	0.775	-3.353
P_{245}	-0.077	1.540	1.467	8.345	-5.075	n.a	n.a
P_{246}	4.502	0.578	2.607	1.578	0.211	5.794	6.004
P_{247}	4.502	0.578	2.606	1.578	0.210	5.793	6.004
P_{248}	2.902	0.578	2.660	4.884	-1.389	3.910	2.521
P_{249}	4.442	0.578	2.778	2.040	0.151	5.807	5.958
P_{250}	3.551	0.578	2.156	2.578	-0.740	4.429	3.689
P_{251}	1.956	0.578	2.215	5.884	-2.335	2.692	0.357
P_{252}	3.484	0.578	2.319	3.040	-0.808	4.428	3.621

Table G.23: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{253}	1.959	0.578	2.217	5.884	-2.333	2.696	0.363
P_{254}	3.488	0.578	2.323	3.040	-0.803	4.435	3.632
P_{255}	1.900	0.578	2.389	6.345	-2.391	2.737	0.346
P_{256}	1.012	0.578	1.771	6.884	-3.279	1.483	-1.796
P_{257}	2.548	0.578	1.884	4.040	-1.743	3.101	1.358
P_{258}	0.947	0.578	1.936	7.345	-3.344	1.515	-1.829
P_{259}	0.947	0.578	1.936	7.345	-3.344	1.515	-1.829
P_{260}	0.000	0.578	1.489	8.345	-4.292	0.380	-3.911
P_{261}	-6.232	5.766	-1.479	6.766	-14.337	n.a	n.a
P_{262}	-6.230	5.766	-1.477	6.766	-14.335	n.a	n.a
P_{263}	-2.303	5.766	1.990	5.845	-10.408	n.a	n.a
P_{264}	-5.782	5.766	-1.278	6.266	-13.886	n.a	n.a
P_{265}	-7.175	5.766	-1.922	7.766	-15.280	n.a	n.a
P_{266}	-3.235	5.766	1.558	6.845	-11.339	n.a	n.a
P_{267}	-6.721	5.766	-1.718	7.266	-14.826	n.a	n.a
P_{268}	-3.241	5.766	1.552	6.845	-11.346	n.a	n.a
P_{269}	-6.728	5.766	-1.725	7.266	-14.833	n.a	n.a
P_{270}	-2.786	5.766	1.757	6.345	-10.890	n.a	n.a
P_{271}	-4.193	5.766	1.100	7.845	-12.298	n.a	n.a
P_{272}	-7.666	5.766	-2.162	8.266	-15.770	n.a	n.a
P_{273}	-3.739	5.766	1.304	7.345	-11.843	n.a	n.a
P_{274}	-3.739	5.766	1.304	7.345	-11.843	n.a	n.a
P_{275}	-4.686	5.766	0.857	8.345	-12.790	n.a	n.a
P_{276}	-5.636	4.805	-1.415	5.805	-13.034	n.a	n.a
P_{277}	-5.634	4.805	-1.414	5.805	-13.032	n.a	n.a
P_{278}	-1.710	4.805	2.049	4.884	-9.108	n.a	n.a
P_{279}	-5.708	4.805	-1.257	6.266	-13.106	n.a	n.a
P_{280}	-6.589	4.805	-1.868	6.805	-13.987	n.a	n.a

Table G.24: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 (M\$)	X_1 (M\$)	S_2 (M\$)	X_2 (M\$)	**Passive NPV** (M\$)	**Value of Flexibility** (M\$)	**eNPV** (M\$)
P_{281}	-2.656	4.805	1.604	5.884	-10.054	n.a	n.a
P_{282}	-6.648	4.805	-1.697	7.266	-14.046	n.a	n.a
P_{283}	-2.654	4.805	1.606	5.884	-10.052	n.a	n.a
P_{284}	-6.655	4.805	-1.704	7.266	-14.053	n.a	n.a
P_{285}	-2.713	4.805	1.778	6.345	-10.111	n.a	n.a
P_{286}	-3.600	4.805	1.160	6.884	-10.998	n.a	n.a
P_{287}	-7.593	4.805	-2.141	8.266	-14.991	n.a	n.a
P_{288}	-3.666	4.805	1.325	7.345	-11.064	n.a	n.a
P_{289}	-3.666	4.805	1.325	7.345	-11.064	n.a	n.a
P_{290}	-4.613	4.805	0.878	8.345	-12.011	n.a	n.a
P_{291}	-3.778	1.961	-1.140	2.961	-9.086	n.a	n.a
P_{292}	-3.778	1.961	-1.139	2.961	-9.086	n.a	n.a
P_{293}	0.158	1.961	2.336	2.040	-5.150	0.278	-4.872
P_{294}	-5.380	1.961	-1.088	6.266	-10.687	n.a	n.a
P_{295}	-4.721	1.961	-1.582	3.961	-10.028	n.a	n.a
P_{296}	-0.800	1.961	1.878	3.040	-6.108	n.a	n.a
P_{297}	-6.320	1.961	-1.527	7.266	-11.627	n.a	n.a
P_{298}	-0.796	1.961	1.882	3.040	-6.104	n.a	n.a
P_{299}	-6.327	1.961	-1.534	7.266	-11.634	n.a	n.a
P_{300}	-2.384	1.961	1.947	6.345	-7.692	n.a	n.a
P_{301}	-1.736	1.961	1.442	4.040	-7.044	n.a	n.a
P_{302}	-7.264	1.961	-1.971	8.266	-12.572	n.a	n.a
P_{303}	-3.337	1.961	1.494	7.345	-8.645	n.a	n.a
P_{304}	-3.337	1.961	1.495	7.345	-8.645	n.a	n.a
P_{305}	-4.284	1.961	1.048	8.345	-9.592	n.a	n.a
P_{306}	0.047	5.384	1.423	6.384	-7.776	n.a	n.a
P_{307}	-0.008	5.384	1.599	6.845	-7.831	n.a	n.a
P_{308}	0.497	5.384	1.624	5.884	-7.326	n.a	n.a

Table G.25: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{309}	-0.966	5.384	1.141	7.845	-8.790	n.a	n.a
P_{310}	-0.446	5.384	1.180	6.884	-8.270	n.a	n.a
P_{311}	-0.512	5.384	1.345	7.345	-8.335	n.a	n.a
P_{312}	-1.459	5.384	0.899	8.345	-9.282	n.a	n.a
P_{313}	1.909	2.540	1.704	3.540	-3.824	1.061	-2.762
P_{314}	0.321	2.540	1.768	6.845	-5.412	n.a	n.a
P_{315}	2.354	2.540	1.898	3.040	-3.379	1.662	-1.717
P_{316}	-0.638	2.540	1.310	7.845	-6.371	n.a	n.a
P_{317}	1.418	2.540	1.462	4.040	-4.315	0.423	-3.892
P_{318}	-0.183	2.540	1.515	7.345	-5.916	n.a	n.a
P_{319}	-1.130	2.540	1.068	8.345	-6.863	n.a	n.a
P_{320}	2.504	1.578	1.757	2.578	-2.523	2.415	-0.108
P_{321}	0.908	1.578	1.815	5.884	-4.118	0.767	-3.351
P_{322}	2.436	1.578	1.920	3.040	-2.590	2.415	-0.176
P_{323}	-0.035	1.578	1.372	6.884	-5.062	n.a	n.a
P_{324}	1.500	1.578	1.485	4.040	-3.526	1.170	-2.356
P_{325}	-0.101	1.578	1.537	7.345	-5.127	n.a	n.a
P_{326}	-1.048	1.578	1.090	8.345	-6.074	n.a	n.a
P_{327}	-8.232	6.766	-2.321	7.766	-17.071	n.a	n.a
P_{328}	-4.291	6.766	1.158	6.845	-13.131	n.a	n.a
P_{329}	-7.778	6.766	-2.118	7.266	-16.617	n.a	n.a
P_{330}	-5.250	6.766	0.700	7.845	-14.089	n.a	n.a
P_{331}	-8.722	6.766	-2.562	8.266	-17.562	n.a	n.a
P_{332}	-4.795	6.766	0.904	7.345	-13.635	n.a	n.a
P_{333}	-5.742	6.766	0.457	8.345	-14.582	n.a	n.a
P_{334}	-7.642	5.805	-2.267	6.805	-15.775	n.a	n.a
P_{335}	-3.709	5.805	1.205	5.884	-11.843	n.a	n.a
P_{336}	-7.702	5.805	-2.096	7.266	-15.835	n.a	n.a

Table G.26: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{337}	-4.653	5.805	0.761	6.884	-12.786	n.a	n.a
P_{338}	-8.646	5.805	-2.540	8.266	-16.779	n.a	n.a
P_{339}	-4.719	5.805	0.926	7.345	-12.852	n.a	n.a
P_{340}	-5.666	5.805	0.479	8.345	-13.799	n.a	n.a
P_{341}	-5.775	2.961	-1.981	3.961	-11.818	n.a	n.a
P_{342}	-1.854	2.961	1.478	3.040	-7.897	n.a	n.a
P_{343}	-7.374	2.961	-1.927	7.266	-13.417	n.a	n.a
P_{344}	-2.790	2.961	1.043	4.040	-8.833	n.a	n.a
P_{345}	-8.318	2.961	-2.371	8.266	-14.361	n.a	n.a
P_{346}	-4.391	2.961	1.095	7.345	-10.434	n.a	n.a
P_{347}	-5.338	2.961	0.648	8.345	-11.381	n.a	n.a
P_{348}	0.416	5.845	1.778	6.845	-7.746	n.a	n.a
P_{349}	0.410	5.845	1.771	6.845	-7.753	n.a	n.a
P_{350}	-3.153	5.845	-1.580	7.266	-11.315	n.a	n.a
P_{351}	-0.543	5.845	1.319	7.845	-8.705	n.a	n.a
P_{352}	-0.088	5.845	1.524	7.345	-8.250	n.a	n.a
P_{353}	-0.088	5.845	1.524	7.345	-8.250	n.a	n.a
P_{354}	-1.035	5.845	1.077	8.345	-9.197	n.a	n.a
P_{355}	0.987	4.884	1.823	5.884	-6.468	n.a	n.a
P_{356}	0.990	4.884	1.826	5.884	-6.466	n.a	n.a
P_{357}	0.931	4.884	1.998	6.345	-6.525	n.a	n.a
P_{358}	0.044	4.884	1.380	6.884	-7.412	n.a	n.a
P_{359}	-0.022	4.884	1.545	7.345	-7.478	n.a	n.a
P_{360}	-0.022	4.884	1.545	7.345	-7.478	n.a	n.a
P_{361}	-0.969	4.884	1.098	8.345	-8.425	n.a	n.a
P_{362}	2.850	2.040	2.098	3.040	-2.515	2.642	0.127
P_{363}	2.854	2.040	2.102	3.040	-2.511	2.649	0.138
P_{364}	1.266	2.040	2.167	6.345	-4.099	1.003	-3.096

Table G.27: Passive NPV, eNPV, and flexibility value for *Airport #2* Scenario #4 portfolios (round-up values) (continued)

Portfolios	S_1 ($M\$$)	X_1 ($M\$$)	S_2 ($M\$$)	X_2 ($M\$$)	**Passive NPV** ($M\$$)	**Value of Flexibility** ($M\$$)	**eNPV** ($M\$$)
P_{365}	1.915	2.040	1.662	4.040	-3.451	1.363	-2.087
P_{366}	0.314	2.040	1.715	7.345	-5.052	n.a	n.a
P_{367}	0.314	2.040	1.715	7.345	-5.052	n.a	n.a
P_{368}	-0.634	2.040	1.268	8.345	-5.999	n.a	n.a
P_{369}	-7.285	6.266	-1.918	7.266	-15.757	n.a	n.a
P_{370}	-7.291	6.266	-1.925	7.266	-15.764	n.a	n.a
P_{371}	-3.349	6.266	1.557	6.345	-11.821	n.a	n.a
P_{372}	-8.229	6.266	-2.362	8.266	-16.701	n.a	n.a
P_{373}	-4.302	6.266	1.104	7.345	-12.774	n.a	n.a
P_{374}	-4.302	6.266	1.104	7.345	-12.774	n.a	n.a
P_{375}	-5.249	6.266	0.657	8.345	-13.721	n.a	n.a
P_{376}	-1.600	6.845	0.920	7.845	-10.498	n.a	n.a
P_{377}	-1.146	6.845	1.124	7.345	-10.043	n.a	n.a
P_{378}	-2.093	6.845	0.677	8.345	-10.990	n.a	n.a
P_{379}	-1.006	5.884	0.980	6.884	-9.196	n.a	n.a
P_{380}	-1.071	5.884	1.146	7.345	-9.262	n.a	n.a
P_{381}	-2.018	5.884	0.699	8.345	-10.209	n.a	n.a
P_{382}	0.862	3.040	1.263	4.040	-5.238	n.a	n.a
P_{383}	-0.739	3.040	1.315	7.345	-6.839	n.a	n.a
P_{384}	-1.686	3.040	0.868	8.345	-7.786	n.a	n.a
P_{385}	-9.281	7.266	-2.761	8.266	-18.488	n.a	n.a
P_{386}	-5.354	7.266	0.705	7.345	-14.561	n.a	n.a
P_{387}	-6.301	7.266	0.258	8.345	-15.509	n.a	n.a
P_{388}	-0.652	6.345	1.324	7.345	-9.182	n.a	n.a
P_{389}	-0.652	6.345	1.324	7.345	-9.182	n.a	n.a
P_{390}	-1.599	6.345	0.877	8.345	-10.129	n.a	n.a
P_{391}	-2.653	7.345	0.477	8.345	-11.917	n.a	n.a

G.3 *Impact of Investment Sequence*

Table G.28: Similar portfolios across each investment scenario considered

Investment in 2 technologies							
Technologies				Portfolios			ID
Scenario #2	**Scenario #3**	**Scenario #4 Y5**	**Scenario #4 Y10**	**Scenario #2**	**Scenario #3**	**Scenario #4**	**ID**
n.a.	T_{30}, T_{28}	T_{30}	T_{28}	n.a.	$P_{1S3}5$	$P_{1S4}1$	$I2_1$
T_{30}, T_3	T_{30}, T_3	T_{30}	T_3	$P_{1S2}4$	$P_{1S3}6$	$P_{1S4}2$	$I2_2$
T_{30}, T_{29}	T_{30}, T_{29}	T_{30}	T_{29}	$P_{1S2}5$	$P_{1S3}7$	$P_{1S4}3$	$I2_3$
T_3, T_{30}	T_3, T_{30}	T_3	T_{30}	$P_{1S2}4$	$P_{1S3}6$	$P_{1S4}8$	$I2_4$
n.a.	T_3, T_{28}	T_3	T_{28}	n.a.	$P_{1S3}8$	$P_{1S4}9$	$I2_5$
T_3, T_{29}	T_3, T_{29}	T_3	T_{29}	$P_{1S2}6$	$P_{1S3}10$	$P_{1S4}10$	$I2_6$
T_{29}, T_{30}	T_{29}, T_{30}	T_{29}	T_{30}	$P_{1S2}5$	$P_{1S3}7$	$P_{1S4}15$	$I2_7$
n.a.	T_{29}, T_{28}	T_{29}	T_{28}	n.a.	$P_{1S3}9$	$P_{1S4}16$	$I2_8$
T_{29}, T_3	T_{29}, T_3	T_{29}	T_3	$P_{1S2}6$	$P_{1S3}10$	$P_{1S4}17$	$I2_9$
Investment in 3 technologies							
Technologies				Portfolios			ID
Scenario #2	**Scenario #3**	**Scenario #4 Y5**	**Scenario #4 Y10**	**Scenario #2**	**Scenario #3**	**Scenario #4**	**ID**
n.a.	T_{30}, T_{28}, T_3	T_{30}	T_{28}, T_3	n.a.	$P_{1S3}11$	$P_{1S4}4$	$I3_1$
n.a.	T_{30}, T_{28}, T_{29}	T_{30}	T_{28}, T_{29}	n.a.	$P_{1S3}12$	$P_{1S4}5$	$I3_2$
T_{30}, T_3, T_{29}	T_{30}, T_3, T_{29}	T_{30}	T_3, T_{29}	$P_{1S2}7$	$P_{1S3}13$	$P_{1S4}6$	$I3_3$
n.a.	T_{30}, T_{28}, T_3	T_3	T_{28}, T_{30}	n.a.	$P_{1S3}11$	$P_{1S4}11$	$I3_4$
T_{30}, T_3, T_{29}	T_{30}, T_3, T_{29}	T_3	T_{30}, T_{29}	$P_{1S2}7$	$P_{1S3}13$	$P_{1S4}12$	$I3_5$
n.a.	T_{28}, T_3, T_{29}	T_3	T_{28}, T_{29}	n.a.	$P_{1S3}14$	$P_{1S4}13$	$I3_6$
n.a.	T_{30}, T_{28}, T_{29}	T_{29}	T_{28}, T_{30}	n.a.	$P_{1S3}12$	$P_{1S4}18$	$I3_7$
T_{30}, T_3, T_{29}	T_{30}, T_3, T_{29}	T_{29}	T_3, T_{30}	$P_{1S2}7$	$P_{1S3}13$	$P_{1S4}19$	$I3_8$
n.a.	T_{28}, T_3, T_{29}	T_{29}	T_{28}, T_3	n.a.	$P_{1S3}14$	$P_{1S4}20$	$I3_9$
n.a.	T_{30}, T_{28}, T_3	T_3, T_{30}	T_{28}	n.a.	$P_{1S3}11$	$P_{1S4}22$	$I3_{10}$
T_{30}, T_3, T_{29}	T_{30}, T_3, T_{29}	T_3, T_{30}	T_{29}	$P_{1S2}7$	$P_{1S3}13$	$P_{1S4}23$	$I3_{11}$
n.a.	T_{30}, T_{28}, T_{29}	T_{30}, T_{29}	T_{28}	n.a.	$P_{1S3}12$	$P_{1S4}25$	$I3_{12}$
T_{30}, T_3, T_{29}	T_{30}, T_3, T_{29}	T_{30}, T_{29}	T_3	$P_{1S2}7$	$P_{1S3}13$	$P_{1S4}26$	$I3_{13}$
T_{30}, T_3, T_{29}	T_{30}, T_3, T_{29}	T_3, T_{29}	T_{30}	$P_{1S2}7$	$P_{1S3}13$	$P_{1S4}28$	$I3_{14}$
n.a.	T_{28}, T_3, T_{29}	T_3, T_{29}	T_{28}	n.a.	$P_{1S3}14$	$P_{1S4}29$	$I3_{15}$

Table G.29: Similar portfolios across each investment scenario (continued)

Investment in 4 technologies							
Technologies				Portfolios			ID
Scenario #2	**Scenario #3**	**Scenario #4 Y5**	**Scenario #4 Y10**	**Scenario #2**	**Scenario #3**	**Scenario #4**	**ID**
n.a.	$T_{30}, T_{28}, T_3, T_{29}$	T_{30}	T_{28}, T_3, T_{29}	n.a.	$P_{1S3}15$	$P_{1S4}7$	$I4_1$
n.a.	$T_{30}, T_{28}, T_3, T_{29}$	T_3	T_{30}, T_{28}, T_{29}	n.a.	$P_{1S3}15$	$P_{1S4}14$	$I4_2$
n.a.	$T_{30}, T_{28}, T_3, T_{29}$	T_{29}	T_{30}, T_{28}, T_3	n.a.	$P_{1S3}15$	$P_{1S4}21$	$I4_3$
n.a.	$T_{30}, T_{28}, T_3, T_{29}$	T_3, T_{30}	T_{29}, T_{28}	n.a.	$P_{1S3}15$	$P_{1S4}24$	$I4_4$
n.a.	$T_{30}, T_{28}, T_3, T_{29}$	T_{30}, T_{29}	T_{28}, T_3	n.a.	$P_{1S3}15$	$P_{1S4}27$	$I4_5$
n.a.	$T_{30}, T_{28}, T_3, T_{29}$	T_3, T_{29}	T_{28}, T_{30}	n.a.	$P_{1S3}15$	$P_{1S4}30$	$I4_6$
n.a.	$T_{30}, T_{28}, T_3, T_{29}$	T_{30}, T_3, T_{29}	T_{28}	n.a.	$P_{1S3}15$	$P_{1S4}31$	$I4_7$

APPENDIX H

SURROGATE MODELING

The creation of surrogate models for the different responses of interest requires executing MACAD for a range of possible inputs. This in turns necessitates selecting the said inputs, and defining the ranges within which they are allowed to vary. These variables, along with their descriptions, baseline values, and respective ranges and units are summarized in Table H.1. In particular, the ranges provided are the outcome of an iterative process during which initial ranges are reduced to ensure that the values taken by each variable lie within the domain of applicability of MACAD. In other words, efforts are made to ensure that the chosen ranges do not result in failed MACAD runs or excessive model fit error (see discussion below). The FileWrapper created to rapidly and automatically run MACAD under different sets of values can be found in Appendix C.

Table H.1: Model variable descriptions, baseline values, ranges and units

Variable descriptions	**Baseline**	**Ranges**	**Units**
Total number of arriving aircraft	99	90-150	Aircraft
Percentage of small aircraft arriving	59	50-80	Percent
Approach speed of small aircraft	110	90-130	knots
Approach speed of medium aircraft	135	110-150	knots
Arrival runway occupancy time for small aircraft	40	20-80	seconds
Arrival runway occupancy time for medium aircraft	45	20-100	seconds
Departure runway occupancy time for small aircraft	49	20-100	seconds
Departure runway occupancy time for medium aircraft	55	20-100	seconds
Arrival taxi average	5	2-10	min
Departure taxi average	5	5-14	min
Minimum separation on approach for a small aircraft following a small aircraft	3	1-6	nmi
Minimum separation on approach for a small aircraft following a medium aircraft	4.5	1-9	nmi
Minimum separation on approach for a medium aircraft following a small aircraft	3	1-6	nmi
Minimum separation on approach for a medium aircraft following a medium aircraft	3.5	1-9	nmi
Minimum inter-departure separation for a small aircraft following a small aircraft	1	0.5-3	nmi
Minimum inter-departure separation for a small aircraft following a medium aircraft	1	0.5-3	nmi
Minimum inter-departure separation for a medium aircraft following a small aircraft	1	0.5-4	nmi
Minimum inter-departure separation for a medium aircraft following a medium aircraft	1	0.5-4	nmi
Minimum distance of the next arrival for a departing aircraft to start rolling	5	2-8	nmi

As discussed, creating a surrogate model requires running the actual code to create a set of data to regress against. However, running MACAD for every variable's potential values, while technically feasible, would be extremely cumbersome and time consuming. A structured and rigorous technique known as Design of Experiments (DOE) is used to address this issue. The concept of design of experiments is particularly well-suited to the creation of surrogates because it purposefully determines the combinations of variables to be run that reduce experimental error and provide the appropriate accuracy for model fitting. As such, this technique allows us to gain a maximum amount of knowledge with a minimum expenditures of experimental effort (number of runs, time, etc.) [238].

A Latin Hypercube with 200 design points is first chosen to create a surrogate model of the average total delay at the airport. The basic fit obtained from the data generated by the DOE exhibits a tail-like pattern when examining the model's residual by predicted plot. The response is thus transformed using a logarithmic function. The following observations can be made when checking for the goodness of fit of the resulting model:

- The R^2 (Table H.2) indicates that much of the variability in the data is accounted for by the model

Table H.2: Summary of Fit

R^2[1]	0.975885
R^2 **adjusted**[2]	0.969464
Root mean square error[3]	0.086256
Mean of Response[4]	2.57118
Observations[5]	196

[1] This term is an estimate of the proportion of the variation in the response around the mean that can be attributed to the model rather than the random error [266]

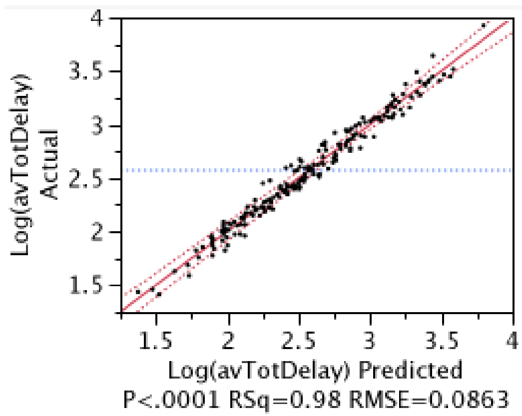
[2] This is an adjusted value of the R^2 to make it more comparable over models with different number of parameters by including the degree of freedom in the calculation [266]

[3] Estimates the standard deviation of the random error [266]

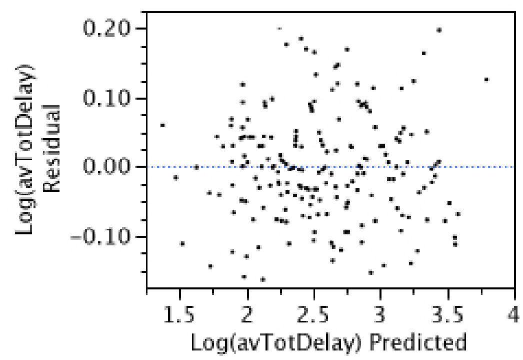
[4] Arithmetic average of the recorded values for the response [266]

[5] Number of observations used to estimate the fit [266]

- From the actual by predicted plot (Figure 1(a)), it appears that the regressed equation is properly modeling the behavior of the data. However, the thickness of the line indicates noise in the data, which is mainly due to the stochastic nature of MACAD. The residual by predicted plot (Figure 1(b)) shows a relatively random scattering of the data point about 0, with no particularly distinguishable pattern



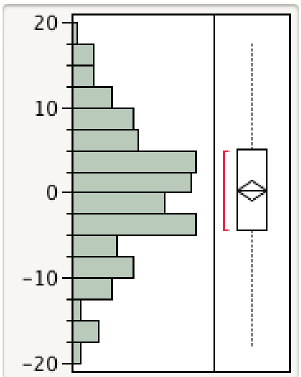
(a) Actual by Predicted plot.



(b) Residual by Predicted plot.

Figure H.1: Model goodness of fit check after transformation and inclusion of higher-order terms.

- The Model Fit Error (MFE), which indicates how well the model fits the data point used to create it, is significant (Figure 2(a)). The Model Representation Error (MRE), which indicates how well the model predicts the actual response, is even more important (Figure 2(b))



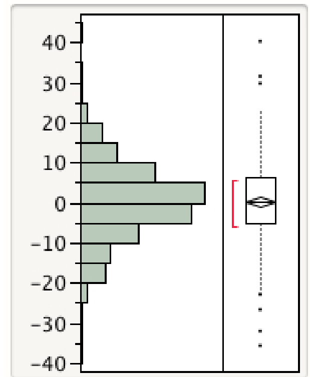
Quantiles

100.0%	maximum	17.7615
99.5%		17.7615
97.5%		15.3605
90.0%		10.9191
75.0%	quartile	5.109
50.0%	median	0.21309
25.0%	quartile	-4.2632
10.0%		-9.6844
2.5%		-15.682
0.5%		-18.276
0.0%	minimum	-18.276

Moments

Mean	0.2904725
Std Dev	7.6088807
Std Err Mean	0.5434915
Upper 95% Mean	1.3623486
Lower 95% Mean	-0.781404
N	196

(a) MFE.



Quantiles

100.0%	maximum	40.1896
99.5%		38.5292
97.5%		20.3512
90.0%		12.4872
75.0%	quartile	6.57173
50.0%	median	0.31468
25.0%	quartile	-4.9679
10.0%		-12.158
2.5%		-20.96
0.5%		-34.999
0.0%	minimum	-35.685

Moments

Mean	0.3632889
Std Dev	10.25913
Std Err Mean	0.6664021
Upper 95% Mean	1.6761456
Lower 95% Mean	-0.949568
N	237

(b) MRE.

Figure H.2: Error distributions.

As previously mentioned, MACAD represents a stochastic process, meaning that similar inputs result in different outputs. Building a surrogate model for such process is particularly difficult. As an attempt to reduce the model representation error a surrogate model of the mean S_μ and and a surrogate model of the standard deviation S_σ of each response of interest are created. Hence, the resulting surrogate of MACAD for a response of interest consists of a normal distribution of mean S_μ and standard deviation S_σ. The process to generate the data necessary for building S_μ is illustrated in Figure H.3. A similar process is applied to obtain S_σ.

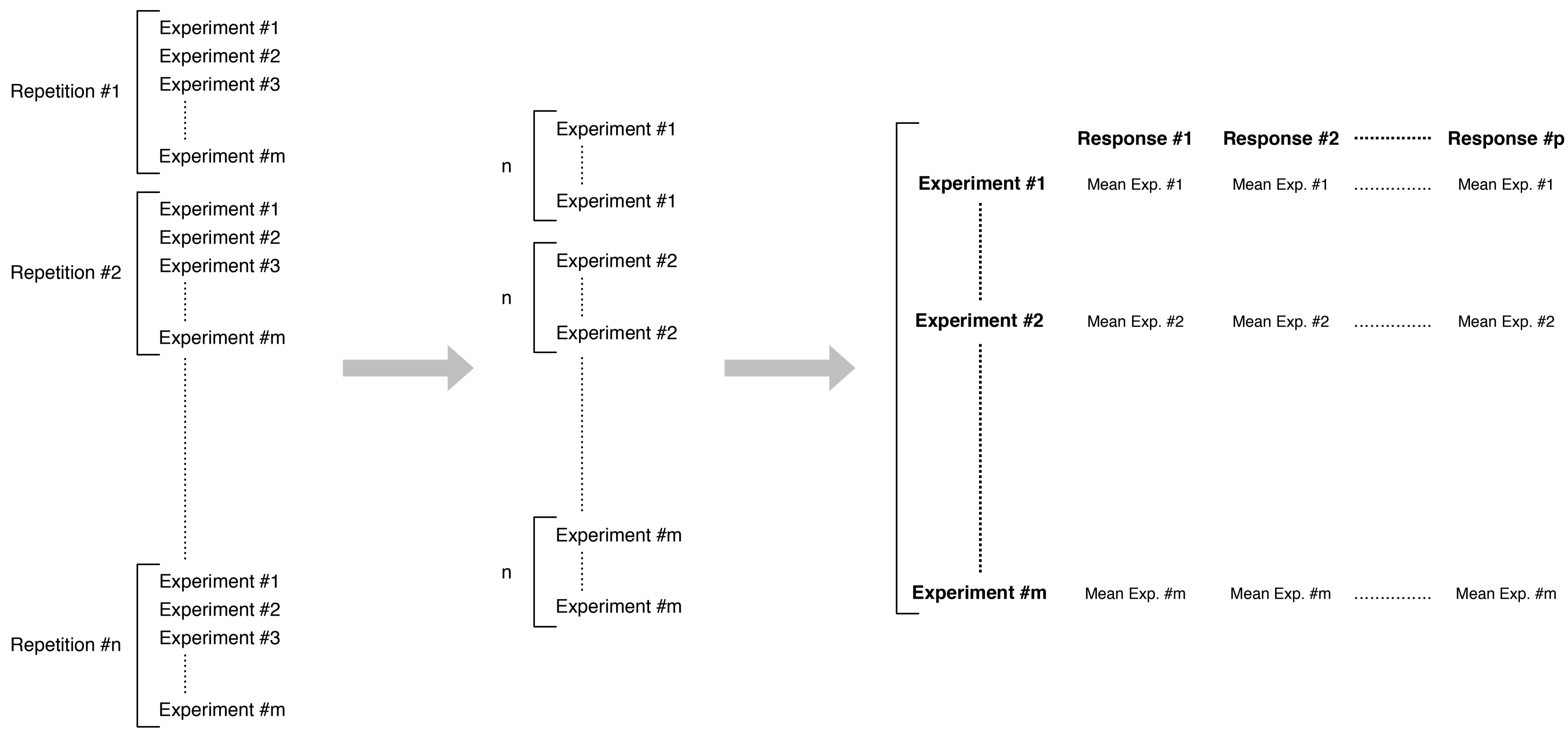
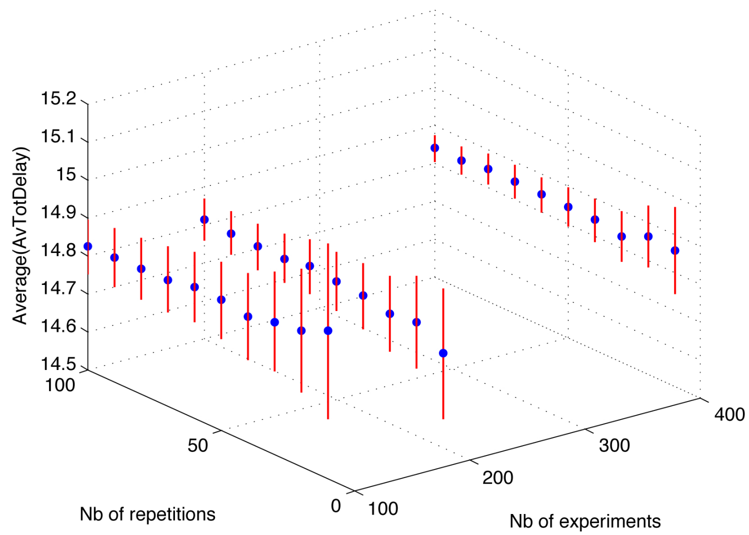


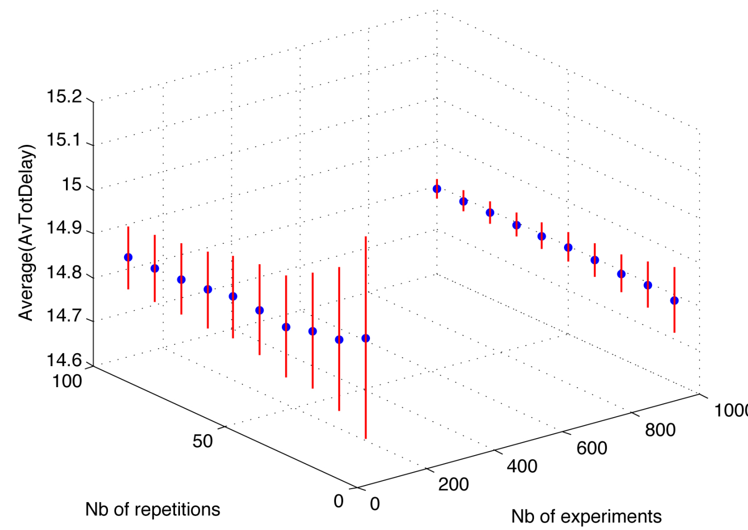
Figure H.3: Surrogate modeling of the mean of the responses.

This process consists in creating experiments using a Latin Hypercube DOE and running them numerous times so as to obtain model fit and model representation errors that are smaller. However, a trade exists between the number of experiments to run, the number of repetitions to conduct, and the time available to run and repeat these experiments. Indeed, both are computationally expensive. Repeating 1000 experiments 50 times, for example, can take up to 5 days on a dual core workstation.

Several DOEs are thus created for different values of m and n: 100, 200 and 1000 experiments repeated up to 100 times. In each instance, the mean, standard deviation and standard error of the response *AvTotalDelay* are computed, as illustrated in Figures H.4 and H.5. In particular, Figure 5(a) shows that, as expected, there is less variability in the value of the mean as the number of repetitions increases. Figure 4(a) shows that, for this model, the standard error is more sensitive to the number of repetitions than it is to the number of experiments. This is particularly well illustrated in Figure 5(b). Hence, repeating a limited number of experiments many times may appear more valuable than repeating a larger number of experiments fewer times, when attempting to reduce the model representation error.

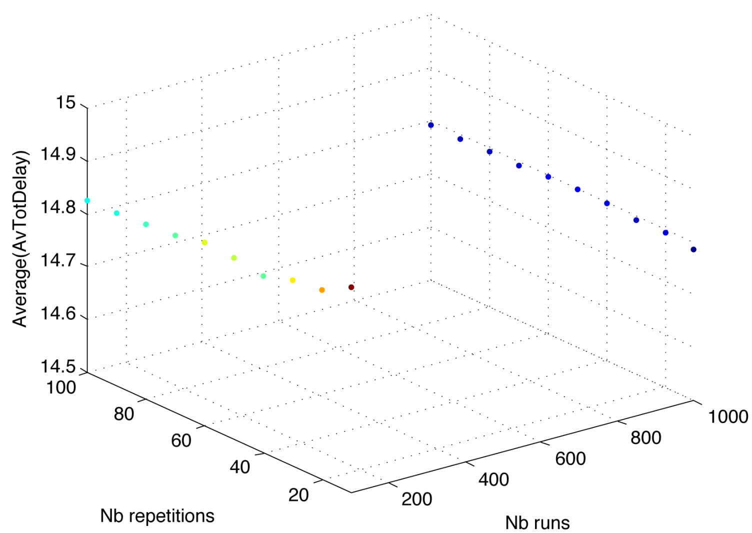


(a) Mean of *AvTotalDelay* and corresponding error bars for 100, 200 and 400 experiments repeated from 10 to 100 times.

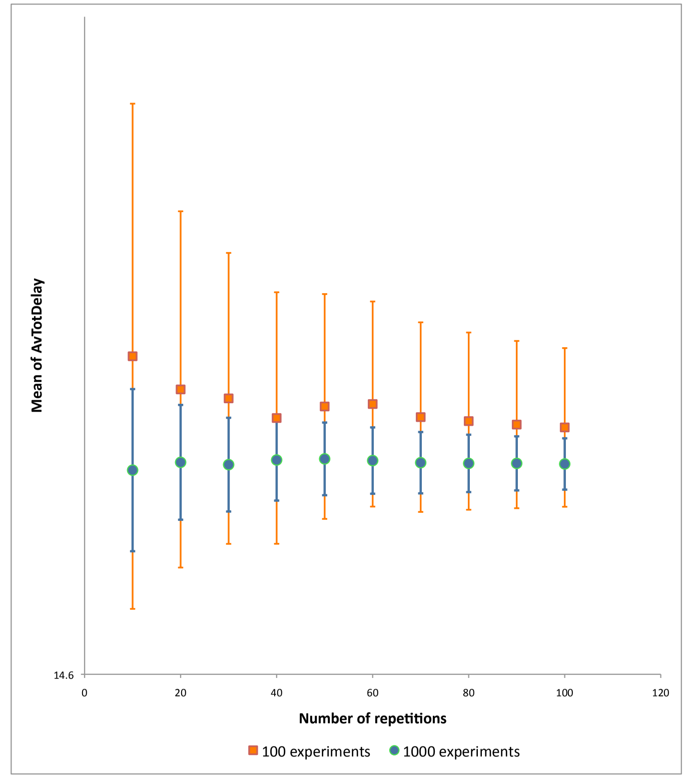


(b) Mean of *AvTotalDelay* and corresponding error bars for 100 and 1000 experiments repeated from 10 to 100 times.

Figure H.4: Variations in the mean and standard error for different numbers of experiments and repetitions.



(a) Variation in the means of *AvTotalDelay* for 100 and 1000 experiments repeated from 10 to 100 times.



(b) Mean of *AvTotalDelay* and corresponding standard error for 100 and 1000 experiments repeated from 10 to 100 times.

Figure H.5: Difference in the means of *AvTotalDelay* and standard error for 100 and 1000 repetitions repeated 100 to 1000 times.

To illustrate this, several DOEs are again created for different values of *m* and *n*: 100, 200, and 400 experiments repeated 50, 100, 150 and 200 times. The mean and standard deviation of each response of interest is then calculated for each identical experiments in each set of experiments/repetitions described above. The goodness of fit of the resulting surrogate models for the mean of *AvTotDelay* is discussed below:

- Tables H.3 through H.5 summarize the R^2 values of each set of experiments/repetitions. In each instance, the variability in the data is accounted for by the model

Table H.3: Summary of Fit for $log(AvTotDelay)$ - 100 experiments repeated 50, 100, 150, and 200 times

	100exp50rep	**100exp100rep**	**100exp150rep**	**100exp200rep**
R^2	1	1	1	1
R^2 adjusted	.	.	.	.
Root mean square error	.	.	.	.
Mean of Response	2.584582	2.579364	2.574735	2.5858
Observations	96	96	97	93

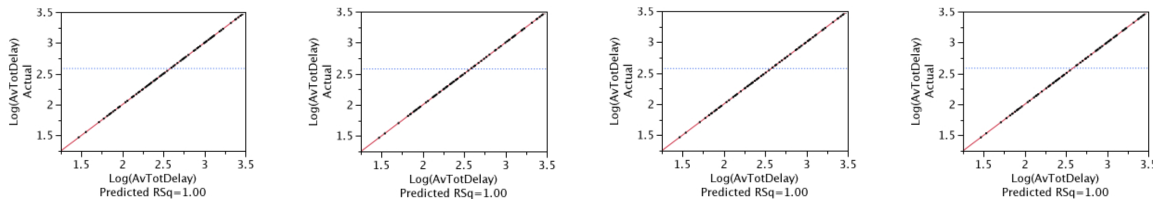
Table H.4: Summary of Fit for $log(AvTotDelay)$ - 200 experiments repeated 50, 100, 150, and 200 times

	200exp50rep	**200exp100rep**	**200exp150rep**	**200exp200rep**
R^2	0.986765	0.983193	0.981133	0.975313
R^2 adjusted	0.981645	0.976801	0.975181	0.969759
Root mean square error	0.065949	0.074426	0.078016	0.084708
Mean of Response	2.578195	2.5846	2.576686	2.581944
Observations	191	197	197	197

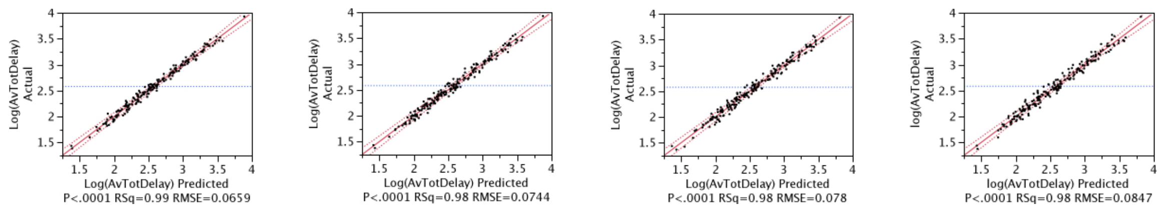
Table H.5: Summary of Fit for $log(AvTotDelay)$ - 400 experiments repeated 50, 100, 150, and 200 times

	400exp50rep	**400exp100rep**	**400exp150rep**	**400exp200rep**
R^2	0.978341	0.978766	0.976929	0.978578
R^2 adjusted	0.974349	0.974916	0.972809	0.97417
Root mean square error	0.075803	0.075133	0.078221	0.076237
Mean of Response	2.591812	2.591268	2.587848	2.587996
Observations	393	392	397	397

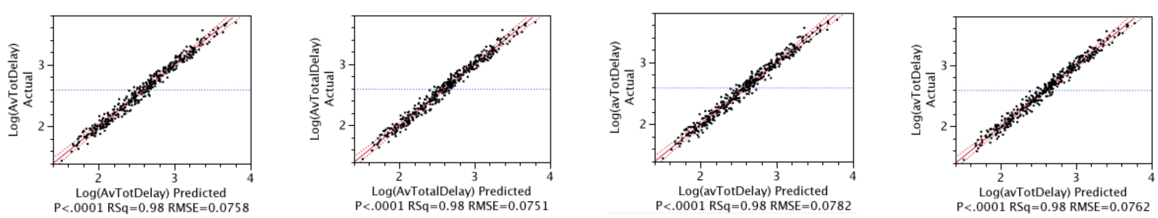
- The actual by predicted plots provided in Figure H.6 show that the data points are relatively evenly distributed along the perfect fit line even though the line created by these data points remains thick for higher number of experiments (400 experiments)



(a) 100exp50rep. **(b)** 100exp100rep. **(c)** 100exp150rep. **(d)** 100exp200rep.



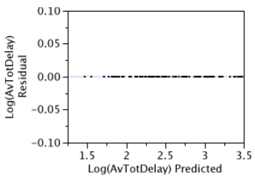
(e) 200exp50rep. **(f)** 200exp100rep. **(g)** 200exp150rep. **(h)** 200exp200rep.

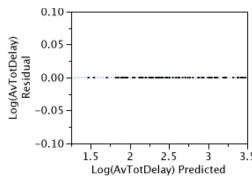


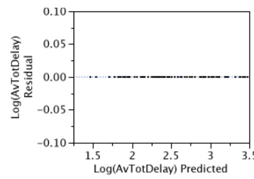
(i) 400exp50rep. **(j)** 400exp100rep. **(k)** 400exp150rep. **(l)** 400exp200rep.

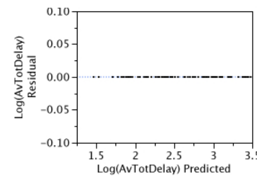
Figure H.6: Actual by predicted plots for each set of experiments/repetitions.

- The residual by predicted plots provided in Figure H.7 show a random scattering of the data points about 0, with no particularly distinguishable pattern for each set of experiments/repetitions considered (in all instances the responses have been transformed using a logarithmic function)

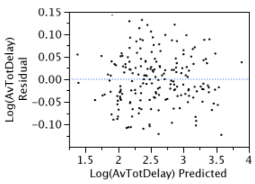


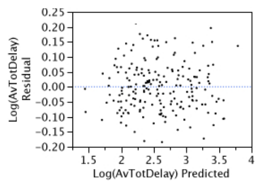


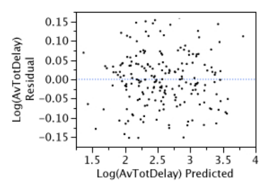


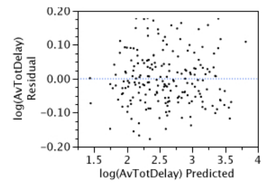


(a) 100exp50rep. **(b)** 100exp100rep. **(c)** 100exp150rep. **(d)** 100exp200rep.

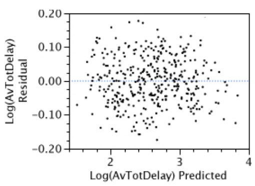


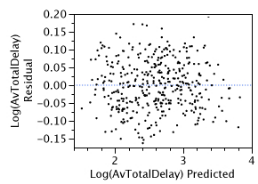


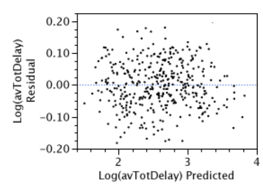


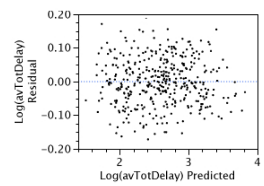


(e) 200exp50rep. **(f)** 200exp100rep. **(g)** 200exp150rep. **(h)** 200exp200rep.





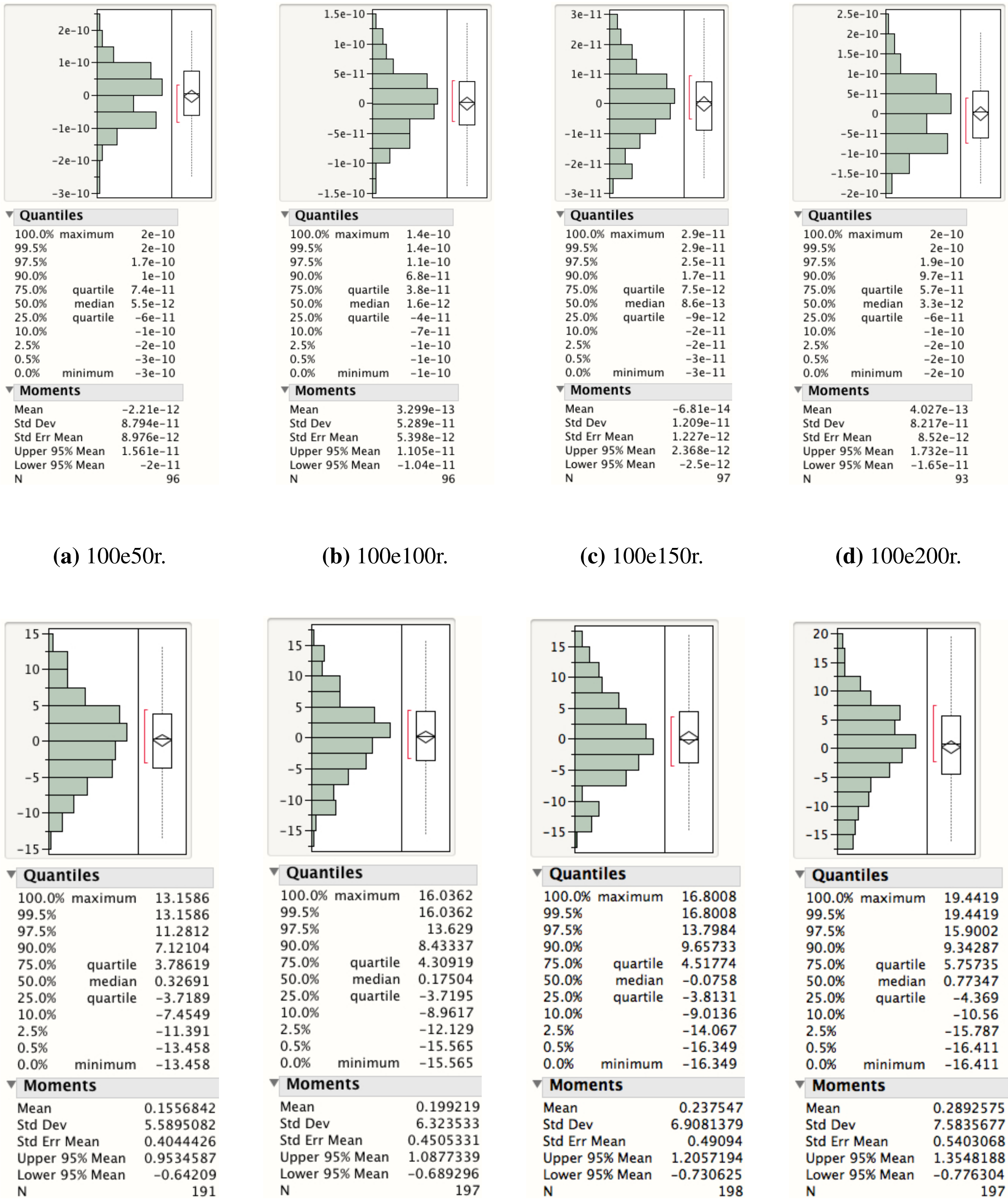




(i) 400exp50rep. **(j)** 400exp100rep. **(k)** 400exp150rep. **(l)** 400exp200rep.

Figure H.7: Residual by predicted plots for each set of experiments/repetitions.

- The model fit error distributions provided in Figures H.8 and H.9 show that the mean of each distribution is close to 0 for each set of experiments/repetitions. However it also shows that the error increases as the number of experiments considered increases as there are more points to fit



Quantiles

		(a) 100e50r	(b) 100e100r	(c) 100e150r	(d) 100e200r
100.0%	maximum	2e-10	1.4e-10	2.9e-11	2e-10
99.5%		2e-10	1.4e-10	2.9e-11	2e-10
97.5%		1.7e-10	1.1e-10	2.5e-11	1.9e-10
90.0%		1e-10	6.8e-11	1.7e-11	9.7e-11
75.0%	quartile	7.4e-11	3.8e-11	7.5e-12	5.7e-11
50.0%	median	5.5e-12	1.6e-12	8.6e-13	3.3e-12
25.0%	quartile	-6e-11	-4e-11	-9e-12	-6e-11
10.0%		-1e-10	-7e-11	-2e-11	-1e-10
2.5%		-2e-10	-1e-10	-2e-11	-2e-10
0.5%		-3e-10	-1e-10	-3e-11	-2e-10
0.0%	minimum	-3e-10	-1e-10	-3e-11	-2e-10

Moments

	(a) 100e50r	(b) 100e100r	(c) 100e150r	(d) 100e200r
Mean	-2.21e-12	3.299e-13	-6.81e-14	4.027e-13
Std Dev	8.794e-11	5.289e-11	1.209e-11	8.217e-11
Std Err Mean	8.976e-12	5.398e-12	1.227e-12	8.52e-12
Upper 95% Mean	1.561e-11	1.105e-11	2.368e-12	1.732e-11
Lower 95% Mean	-2e-11	-1.04e-11	-2.5e-12	-1.65e-11
N	96	96	97	93

(a) 100e50r. **(b)** 100e100r. **(c)** 100e150r. **(d)** 100e200r.

Quantiles

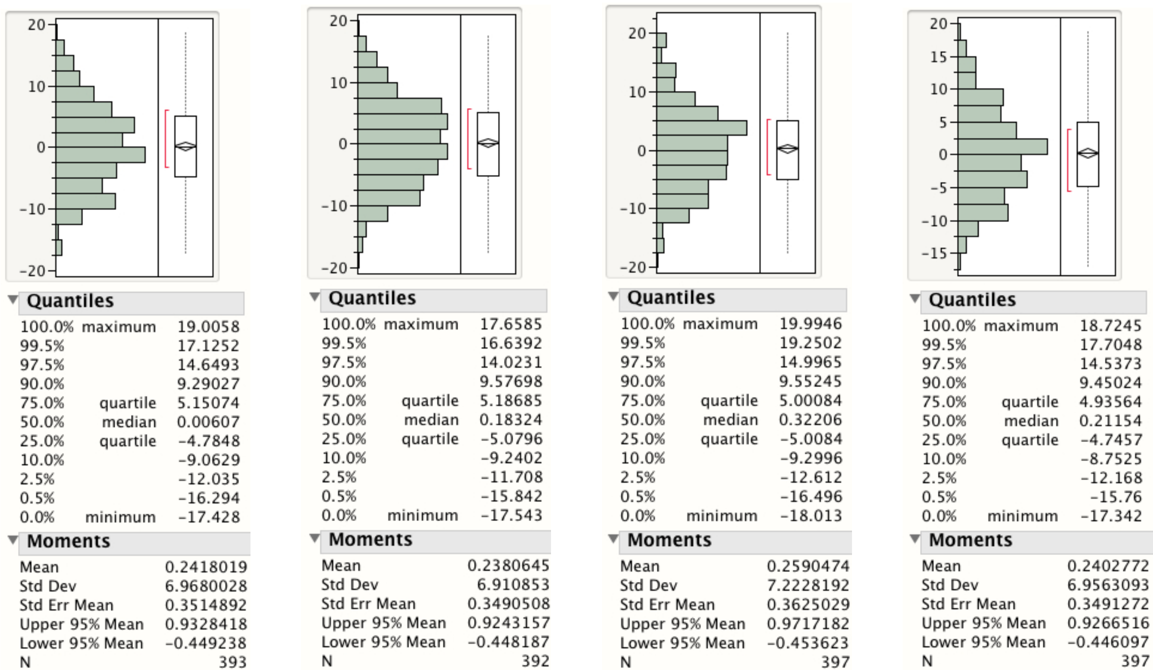
		(e) 200e50r	(f) 200e100r	(g) 200e150r	(h) 200e200r
100.0%	maximum	13.1586	16.0362	16.8008	19.4419
99.5%		13.1586	16.0362	16.8008	19.4419
97.5%		11.2812	13.629	13.7984	15.9002
90.0%		7.12104	8.43337	9.65733	9.34287
75.0%	quartile	3.78619	4.30919	4.51774	5.75735
50.0%	median	0.32691	0.17504	-0.0758	0.77347
25.0%	quartile	-3.7189	-3.7195	-3.8131	-4.369
10.0%		-7.4549	-8.9617	-9.0136	-10.56
2.5%		-11.391	-12.129	-14.067	-15.787
0.5%		-13.458	-15.565	-16.349	-16.411
0.0%	minimum	-13.458	-15.565	-16.349	-16.411

Moments

	(e) 200e50r	(f) 200e100r	(g) 200e150r	(h) 200e200r
Mean	0.1556842	0.199219	0.237547	0.2892575
Std Dev	5.5895082	6.323533	6.9081379	7.5835677
Std Err Mean	0.4044426	0.4505331	0.49094	0.5403068
Upper 95% Mean	0.9534587	1.0877339	1.2057194	1.3548188
Lower 95% Mean	-0.64209	-0.689296	-0.730625	-0.776304
N	191	197	198	197

(e) 200e50r. **(f)** 200e100r. **(g)** 200e150r. **(h)** 200e200r.

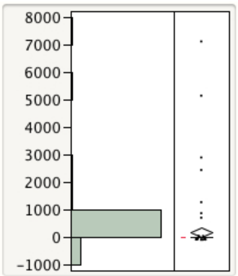
Figure H.8: Model fit error distributions for each set of experiments/repetitions.



(a) 400e50r. **(b)** 400e100r. **(c)** 400e150r. **(d)** 400e200r.

Figure H.9: Model fit error distributions for each set of experiments/repetitions (continued).

- Figures H.10 and H.11 show that, as expected, the model representation error is larger than the model fit error. Cases with a smaller number of experiments exhibit higher model representation errors: the predictive capability of the model at off design points (points not used to generate the model) is limited because fewer points are used to create the surrogate. Also, the model representation error decreases as the number of experiments increases. In addition, it appears that the number of repetitions has a stronger impact on the error for lower number of experiments that for higher number.



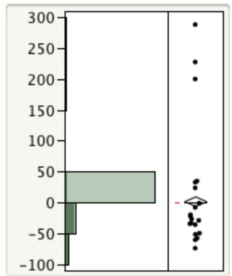
Quantiles

100.0%	maximum	7111.98
99.5%		7111.98
97.5%		3059.35
90.0%		1.6e-10
75.0%	quartile	7.7e-11
50.0%	median	4.8e-12
25.0%	quartile	-8e-11
10.0%		-10.592
2.5%		-95.842
0.5%		-99.636
0.0%	minimum	-99.636

Moments

Mean	169.43234
Std Dev	888.88997
Std Err Mean	82.531361
Upper 95% Mean	332.91109
Lower 95% Mean	5.9536006
N	116

(a) 100e50r.



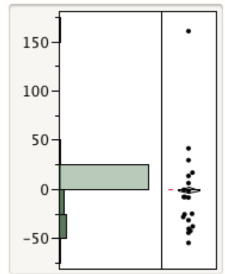
Quantiles

100.0%	maximum	287.837
99.5%		287.837
97.5%		201.864
90.0%		9.5e-11
75.0%	quartile	3.8e-11
50.0%	median	-4e-12
25.0%	quartile	-6e-11
10.0%		-20.331
2.5%		-57.763
0.5%		-73.761
0.0%	minimum	-73.761

Moments

Mean	2.6352461
Std Dev	41.696334
Std Err Mean	3.8714074
Upper 95% Mean	10.303759
Lower 95% Mean	-5.033267
N	116

(b) 100e100r.



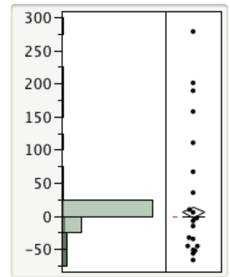
Quantiles

100.0%	maximum	160.546
99.5%		160.546
97.5%		29.8227
90.0%		1.9e-11
75.0%	quartile	7.6e-12
50.0%	median	-1e-12
25.0%	quartile	-1e-11
10.0%		-8.1315
2.5%		-42.719
0.5%		-54.906
0.0%	minimum	-54.906

Moments

Mean	-0.798456
Std Dev	19.030244
Std Err Mean	1.7593467
Upper 95% Mean	2.6861513
Lower 95% Mean	-4.283064
N	117

(c) 100e150r.



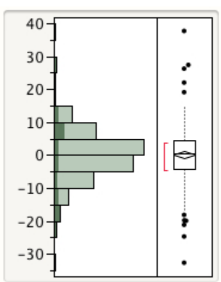
Quantiles

100.0%	maximum	278.239
99.5%		278.239
97.5%		190.659
90.0%		1.9e-10
75.0%	quartile	6.5e-11
50.0%	median	1.7e-12
25.0%	quartile	-7e-11
10.0%		-2.0678
2.5%		-53.257
0.5%		-66.681
0.0%	minimum	-66.681

Moments

Mean	5.6599953
Std Dev	43.539923
Std Err Mean	4.0958914
Upper 95% Mean	13.775479
Lower 95% Mean	-2.455488
N	113

(d) 100e200r.



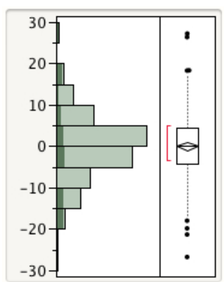
Quantiles

100.0%	maximum	37.6448
99.5%		35.9958
97.5%		15.3833
90.0%		9.11771
75.0%	quartile	4.47952
50.0%	median	0.40094
25.0%	quartile	-4.155
10.0%		-8.7802
2.5%		-18.517
0.5%		-31.434
0.0%	minimum	-32.708

Moments

Mean	0.1184622
Std Dev	8.2059905
Std Err Mean	0.5399145
Upper 95% Mean	1.182273
Lower 95% Mean	-0.945349
N	231

(e) 200e50r.



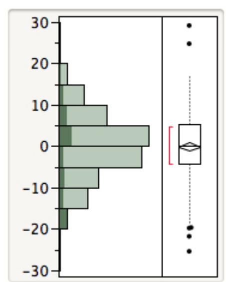
Quantiles

100.0%	maximum	27.2183
99.5%		27.0565
97.5%		16.2747
90.0%		9.70588
75.0%	quartile	4.45513
50.0%	median	0.14841
25.0%	quartile	-4.3116
10.0%		-10.782
2.5%		-16.539
0.5%		-25.745
0.0%	minimum	-26.779

Moments

Mean	0.062092
Std Dev	8.0031103
Std Err Mean	0.5198579
Upper 95% Mean	1.0862468
Lower 95% Mean	-0.962063
N	237

(f) 200e100r.



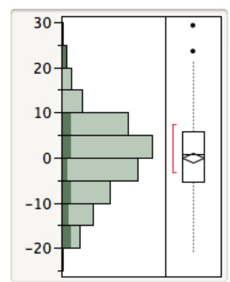
Quantiles

100.0%	maximum	29.1697
99.5%		28.3335
97.5%		16.2947
90.0%		11.1025
75.0%	quartile	5.24134
50.0%	median	0.13354
25.0%	quartile	-4.2644
10.0%		-10.71
2.5%		-17.982
0.5%		-24.714
0.0%	minimum	-25.403

Moments

Mean	-0.002226
Std Dev	8.162633
Std Err Mean	0.53022
Upper 95% Mean	1.0423427
Lower 95% Mean	-1.046795
N	237

(g) 200e150r.



Quantiles

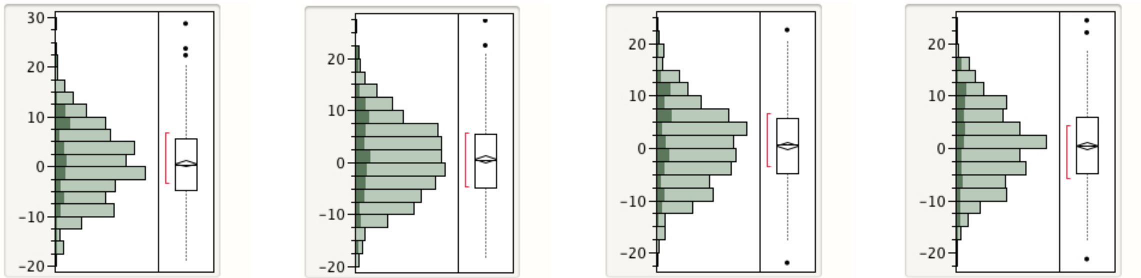
100.0%	maximum	29.2792
99.5%		28.1935
97.5%		18.2634
90.0%		9.63921
75.0%	quartile	5.79578
50.0%	median	0.69357
25.0%	quartile	-5.3803
10.0%		-12.588
2.5%		-16.432
0.5%		-20.634
0.0%	minimum	-21.014

Moments

Mean	-0.011519
Std Dev	8.6965222
Std Err Mean	0.5648998
Upper 95% Mean	1.1013718
Lower 95% Mean	-1.124409
N	237

(h) 200e200r.

Figure H.10: Model representation error distributions for each set of experiments/repetitions.



Quantiles

		(a)	(b)	(c)	(d)
100.0%	maximum	28.7026	27.2263	22.559	24.3793
99.5%		23.183	21.864	20.4872	20.7524
97.5%		15.8336	15.5337	15.5056	15.9792
90.0%		10.2585	10.4622	10.211	10.3772
75.0%	quartile	5.70048	5.54739	5.76419	5.88184
50.0%	median	0.26349	0.42096	0.60641	0.46705
25.0%	quartile	−4.7595	−4.9009	−4.9007	−4.7952
10.0%		−9.0629	−9.2505	−9.3614	−9.2319
2.5%		−12.463	−12.575	−13.995	−14.016
0.5%		−17.187	−17.123	−18.016	−17.647
0.0%	minimum	−19.36	−18.684	−21.967	−21.255

Moments

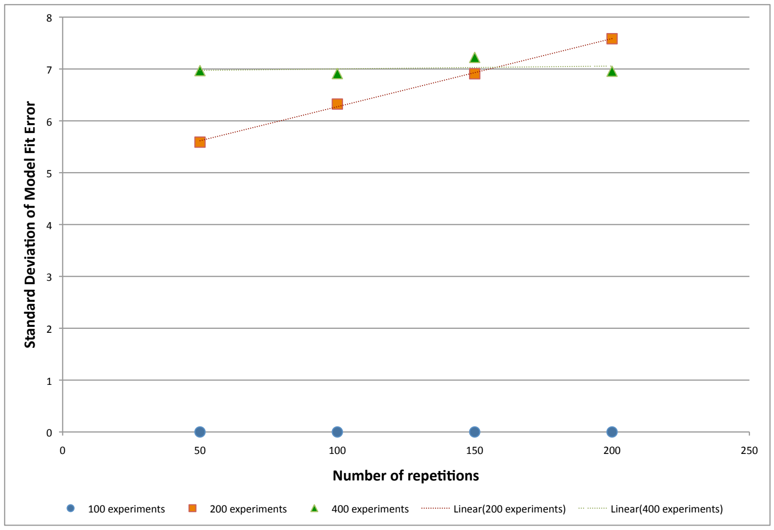
	(a)	(b)	(c)	(d)
Mean	0.6193177	0.6216971	0.4639201	0.4778345
Std Dev	7.5127242	7.4138917	7.5696031	7.531722
Std Err Mean	0.3454354	0.341252	0.3476834	0.3448539
Upper 95% Mean	1.2980992	1.2922619	1.1471151	1.1554586
Lower 95% Mean	−0.059464	−0.048868	−0.219275	−0.19979
N	473	472	474	477

(a) 400e50r. **(b)** 400e100r. **(c)** 400e150r. **(d)** 400e200r.

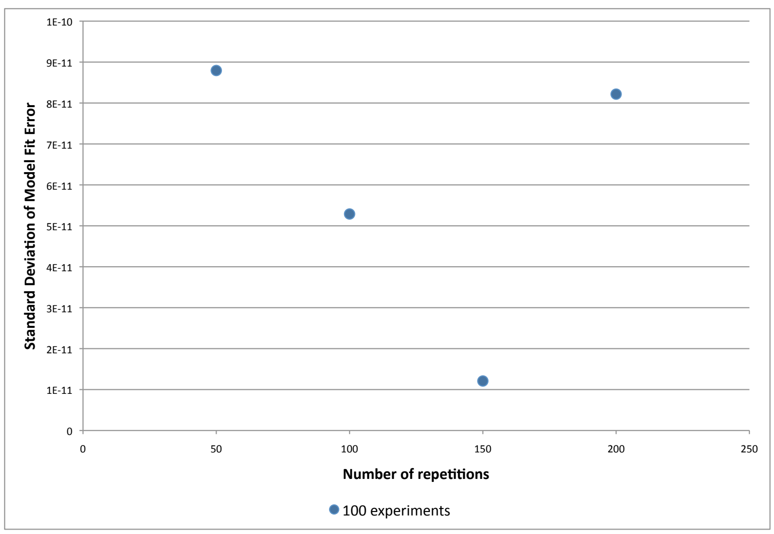
Figure H.11: Model representation error distributions for each set of experiments/repetitions (Continued).

H.0.1 Observations

- As expected the MRE is larger than the MFE. Also, although its mean is close to 0, its standard deviation remains too large, even for the highest number of experiments and repetitions.
- The variability in model fit error and model representation error is smaller for higher number of experiments, as illustrated in Figures H.12 and H.13.

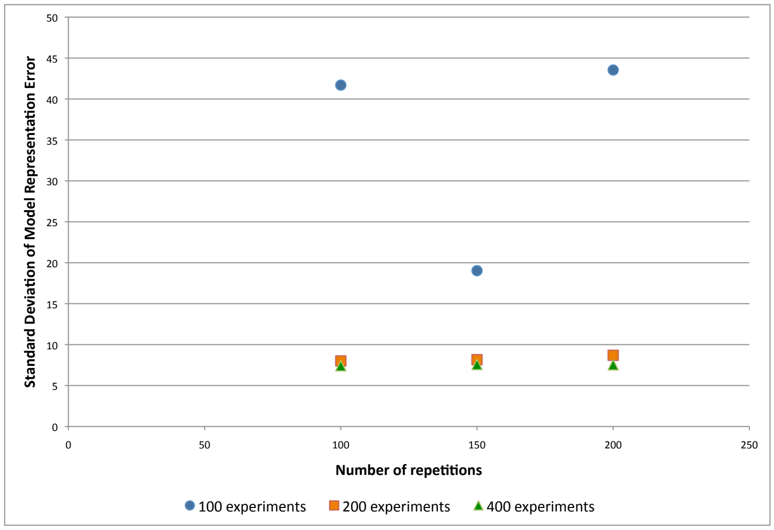


(a) MFE standard deviation for each set of experiments/repetitions.

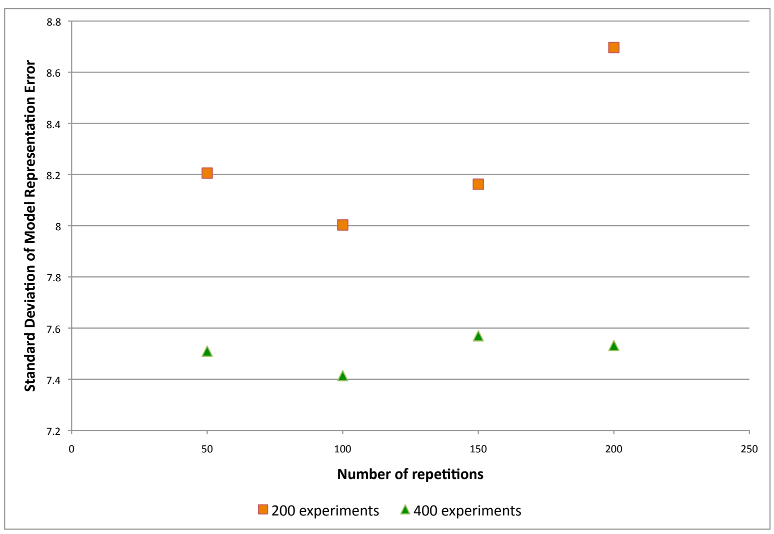


(b) MFE standard deviation for each set of experiments/repetitions (zoomed).

Figure H.12: Variation in model fit error for different sets of experiments/repetitions.



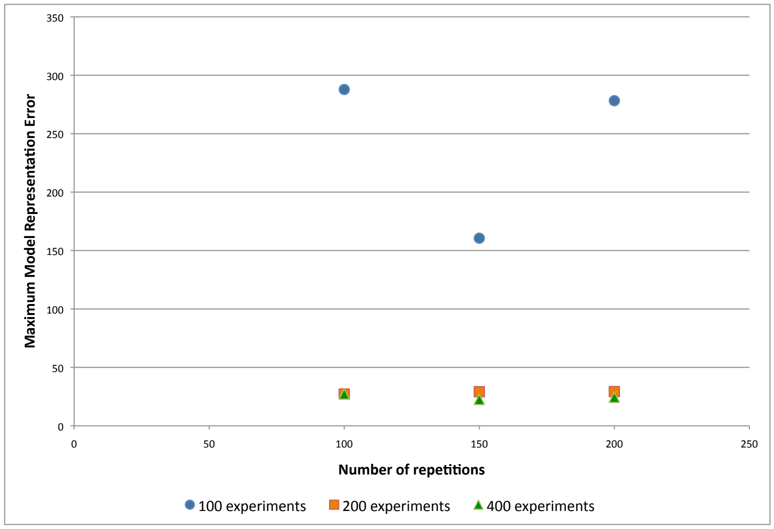
(a) MRE standard deviation for each set of experiments/repetitions.



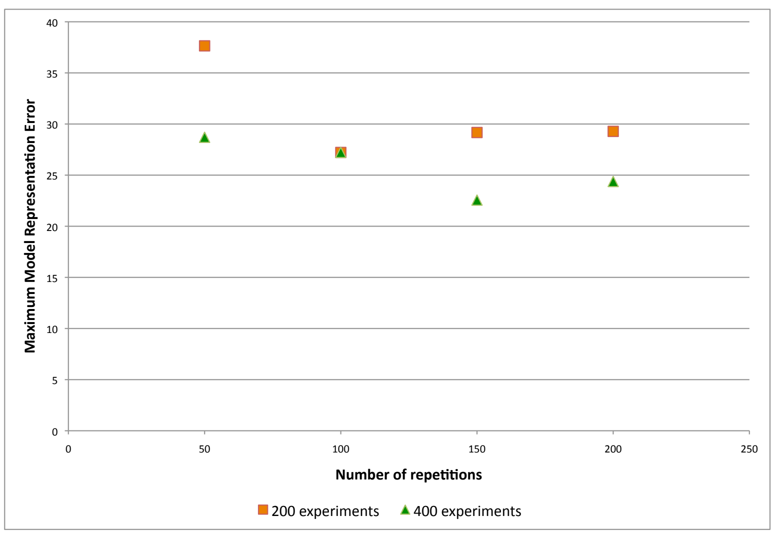
(b) MRE standard deviation for each set of experiments/repetitions (zoomed).

Figure H.13: Variation in model representation error for different sets of experiments/repetitions.

- The maximum model representation error is smaller for higher number of experiments, as illustrated in Figures 14(a) and 14(b).



(a) Maximum model representation error for each set of experiments/repetitions.



(b) Maximum model representation error for each set of experiments/repetitions (zoomed).

Figure H.14: Model representation error distributions for each set of experiments/repetitions (Continued).

- The model fit error is bigger for higher number of experiments, as illustrated in Figure H.15

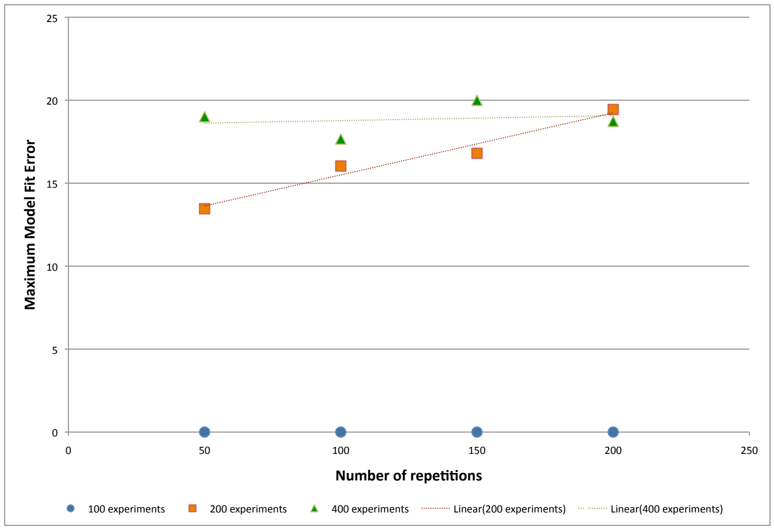


Figure H.15: Maximum model fit error for each set of experiments/repetitions.

Hence, it does not appear, for this particular problem, that building a surrogate of the mean allows to reduce the model fit error to an acceptable level. There is still too much noise in the data. The results discussed above were obtained using a stepwise to fit the points. Previous efforts using Neural Nets with different number of nodes and hidden layers resulted in similar results in terms of R^2, MFEs and MREs. Attempts to discretize the ranges of the variables and to build surrogates for each discretization did not result in a lower model representation error either.

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VITA

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